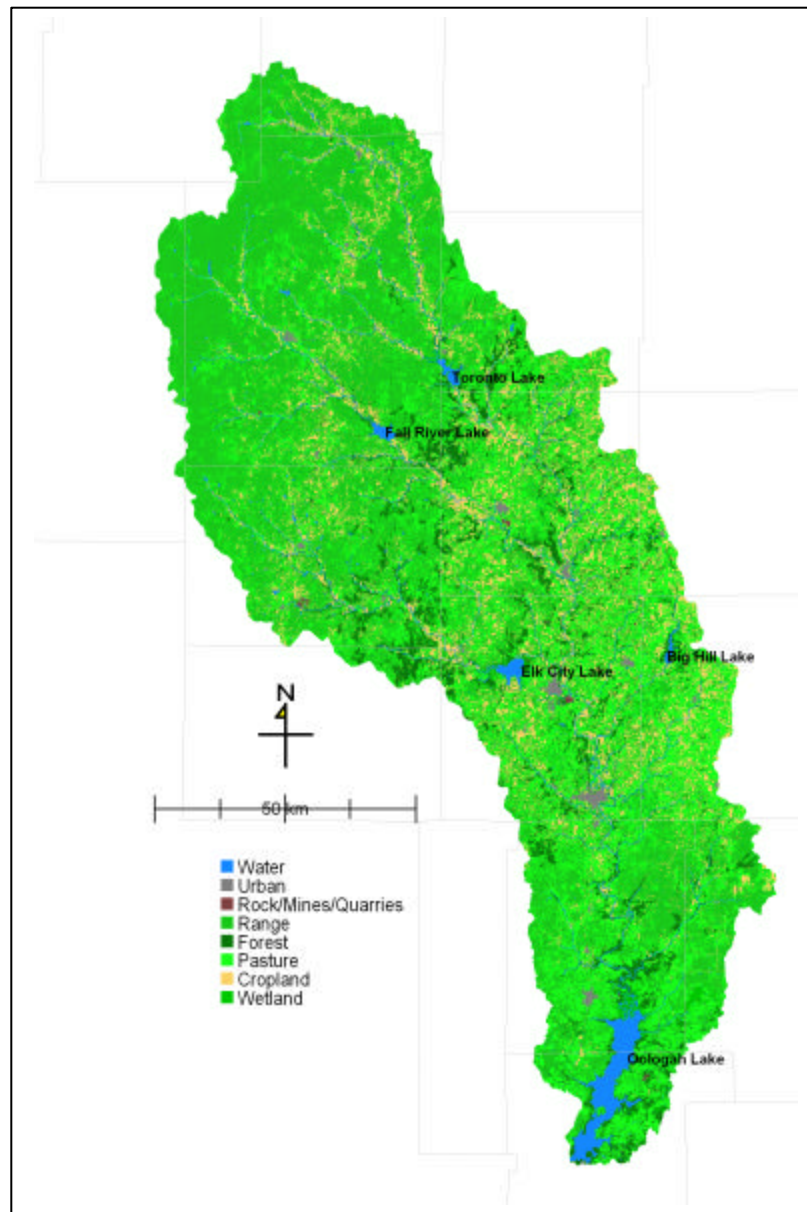


OOLOGAH LAKE, OKLAHOMA WATERSHED STUDY

YEAR 2 INTERIM REPORT OF FINDINGS: OCTOBER 2000-SEPTEMBER 2001



**US Army Corps
of Engineers®**

Tulsa District
Planning, Environmental,
and Regulatory Division

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**OOLOGAH LAKE, OKLAHOMA, WATERSHED STUDY
YEAR 2 INTERIM REPORT OF FINDINGS:
OCTOBER 2000 – SEPTEMBER 2001**

**Prepared for:
Oklahoma Water Resources Board (OWRB)
Oklahoma City, Oklahoma
and
Tulsa Metropolitan Utilities Authority (TMUA)
Tulsa, Oklahoma**

**Prepared under:
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**Prepared by:
U.S. Army Corps of Engineers
Tulsa District**

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EXECUTIVE SUMMARY

This report provides a summary of data and findings obtained by the U.S. Army Corps of Engineers (USACE), Tulsa District (TD) during a second year of investigation for the Oologah Lake, Oklahoma, Watershed Study. This phase of investigation was conducted under the USACE Planning Assistance to States (PAS) Program. The project sponsor was the Oklahoma Water Resources Board (OWRB) with participation by the Tulsa Municipal Utilities Authority (TMUA). Results of previous investigations for the initial year of study (April to September 2000) were documented in an earlier TD report (USACE 2001). In an effort to maintain project continuity, this report includes presentation and analysis of data collected during the period October 2000 to September 2001.

Activities for this phase of study included the following major tasks: (1) collection of in-lake data at Oologah Lake in a manner similar to that established during the initial year of study, (2) continuous monitoring of key parameters, water sample collection and analysis, and load estimation for major tributaries to Oologah Lake, (3) continued refinement and calibration of a lake hydrodynamic and water quality model capable of simulating effects of management strategies for Oologah Lake, and (4) quantification of land use and initial setup and evaluation of a watershed model applicable to the entire Verdigris River Basin above Oologah Dam. Results from each of these areas of evaluation are detailed in this report.

A significant portion of this report is devoted not only to presentation of additional water quality data collected during the study period, but also to comparison of these findings to data collected during the initial year of study. Hydrologic conditions in the Verdigris River Basin were significantly different during the two periods of study, and analysis of resulting differences in water quality conditions provided insight into limnological dynamics of the system.

As a quick reference to summary statistics for data collected during this investigation, the following tables can be consulted: tributary data (Tables 3.2-1 through 3.2-7, pp. 3-7 to 3-16), reservoir data (Tables 3.3-1 and 3.3-2, pp. 3-37 to 3-38 and 3-39 to 3-40, respectively), and sediment data (Table 3.6-1, p. 3-93).

Major findings and conclusions of the study are provided below. Findings are provided separately for tributary data, Oologah Lake general limnology, water quality contaminants, sediment sampling and analysis, reservoir modeling, and watershed land-use and modeling.

OOLOGAH LAKE TRIBUTARIES (VERDIGRIS RIVER AND BIG CREEK)

1. Consistent with results obtained during the initial year of study (2000), substantial differences in concentrations of several key constituents were noted in samples from the two tributaries. Most notably, concentrations of turbidity, total suspended solids, chlorophyll *a*, Kjeldahl nitrogen, and total phosphorus were substantially higher in samples from the Verdigris River relative to those from Big Creek. For both study years combined, average concentrations of total phosphorus, nitrogen, and nephelometric turbidity in samples from the Verdigris River were approximately twice those measured in samples from Big Creek.

2. Total phosphorus (P) concentrations in both tributaries were high, though lower than those measured for the same time period in 2000. For April through September 2001, mean and median total P were 0.11 and 0.09 mg/l, respectively, in samples from the Verdigris River and 0.07 and 0.04 mg/l, respectively, in samples from Big Creek. For the Verdigris River, statistically significant differences in mean concentrations of total P, dissolved total P, and dissolved ortho-P were noted between sampling periods (year 2000 means > year 2001 means). Based on median values, approximately one-half of total P concentrations in samples from both systems were associated with suspended matter.

3. For Verdigris River inflows (April 2000 through September 2001), nitrogen to phosphorus ratios (N:P) were 6.1 and 10.8 based on mean and median concentrations, respectively.

4. Temporal changes in nephelometric turbidity closely mirrored the hydrograph in both tributaries. Based on continuous monitoring data for the study period, mean and median turbidity values were 119.65 and 40.80 nephelometric turbidity units (NTU), respectively, for the Verdigris River (n = 4,294) and 46.95 and 18.10 NTU, respectively, for Big Creek (n = 2,640). For the entire period of April 2000 through July 2001, average turbidity in the Verdigris River was 46.33 (n = 9,882).

5. Tributary-specific multiple regression equations for estimating important physical and chemical parameters based on continuously monitored field data were developed and appeared reasonable for use in estimation of delivered loads. For the Verdigris River, selected equations based on the entire period of record (2000 and 2001) were capable of explaining approximately 83, 58, 84, and 86% of the observed variability in total suspended solids, total organic carbon, total nitrogen, and total phosphorus, respectively. The R^2 value for the total P equation was improved by 0.13 with the addition of data from the second year of study. A similarly-derived equation was capable of explaining 97% of the observed variability in total P in Big Creek samples. Nephelometric turbidity was among selected surrogate parameters in regression equations for most constituents.

6. Multiple regression equations were used to estimate average combined daily loads (kg/day) from both tributaries for the April 2000 to September 2001 period as follows: total P (1,690), total nitrogen (11,350), and total suspended solids (1,340,620 kg/day or approximately 1,500 tons/day). Of these loads, relative contributions from the Verdigris River were as follows: total P (92%), total N (96%), and total suspended solids (87%).

OOLOGAH LAKE (GENERAL LIMNOLOGY)

1. Total P concentrations for the study period ranged from 0.02 to 0.30 mg/l with a mean and median concentration of 0.098 and 0.076 mg/l, respectively. Both concentration and variability increased from Oologah Dam to uplake stations, particularly in shallow water areas above Winganon Bridge. Total P concentrations were strongly correlated with suspended solids. Mean and median total P concentrations for this study period were approximately 11 and 8%

lower, respectively, than those for the same period in 2000, but this difference was not statistically significant.

2. Measurable concentrations of dissolved ortho-P were reported for nearly every sample collected during this study period. Concentrations of dissolved ortho-P ranged from 0.01 to 0.12 mg/l with nearly identical mean and median values of 0.044 and 0.046 mg/l, respectively. These values were nearly identical to those observed during the initial year of study.

3. Mean lake-wide nitrogen to phosphorus ratio (N:P) was 8.3. This value was nearly identical to that measured in 2000 (8.0). Accordingly, under conditions when nutrient concentrations limit algal growth, N:P derived during both study periods support a hypothesis of nitrogen limitation in Oologah Lake – a condition somewhat unusual for reservoirs of the region.

4. Consistent with the first year of study, turbidity values in Oologah Lake frequently exceeded the State of Oklahoma lake water quality standard of 25 NTU. Surface field turbidity across all sampling sites and dates ($n = 41$) ranged from 8 to 282.1 NTU with mean and median values of 62.7 and 49.5 NTU, respectively. Mean and median surface turbidity values were 9.5 and 7.7% higher relative to surface turbidity in 2000 though differences were not statistically significant. Turbidity levels were greatest and highly variable at up-lake stations relative to those at near-dam water supply intake locations.

5. Lake-wide concentrations of chlorophyll *a*, a commonly used indicator of algal production, ranged from 1.2 to 25.6 $\mu\text{g/l}$ with mean and median concentrations of 7.7 and 6.9 $\mu\text{g/l}$, respectively. While median whole lake chlorophyll concentrations were not significantly different between study years, chlorophyll *a* concentrations exhibited lower variability in 2001 relative to those measured in the initial year of study. On several dates during the study, vertical profiles (1 m increments) of both chlorophyll *a* and pheophytin *a* (a degradation pigment and by-product of algal senescence) were measured at Oologah Dam. Preliminary findings are presented in this report.

6. For this study period, Secchi depths (SD) ranged from 0.09 to 1.40 m with an overall lake average of 0.48 m. Mean SD was highest near Oologah Dam (0.78 m) and lowest near at the upper end of the lake (0.17 m).

7. Average estimates of euphotic zone depth (Z_{eu}) for this study period were very similar to those obtained during the initial year of study. Data from both years reveal the presence of a very limited layer of light intensity suitable for algal production in Oologah Lake. Calculated photic zone depths ranged from 0.38 to 4.97 m with an overall average of 1.75 m (5.7 feet) for the lake through the sampling period. When data for both study periods were combined, mean photic zone depths ranged from 0.82 m (2.7 feet) at the upper end of Oologah Lake to 2.74 m (9 feet) near Oologah Dam. Site-specific ratios of $Z_{\text{eu}}:\text{SD}$ were derived permitting estimation of photic zone depth based solely on SD. For all data (2000 – 2001), these values ranged from 3.64 to 4.52.

8. During this study period, patterns of both thermal and dissolved oxygen (DO) stratification were fairly similar to those observed during the initial year of study. However, observed differences included a more prolonged period of hypolimnetic anoxia at near-dam sites and differences in overall magnitude of temperature decreases with depth in the lower portion of the reservoir. Relative contributions of reservoir outflow and meteorology to vertical stratification patterns are discussed.

9. A new bottom contour map of Oologah Lake was completed using previously-collected data consisting of approximately 1.2 million georeferenced data points with z-values corresponding to bottom surface elevation. This updated information was employed in reservoir modeling exercises. The map is available in geographic information system (GIS) format.

10. A significant task during this study period was continued set up and calibration of a hydrodynamic and water quality model (CE-QUAL-W2) for Oologah Lake. The ultimate goal of this model will be to provide a valuable tool for evaluation of lake management strategies. The model computational grid was refined using updated bathymetric data, and the model was able to successfully reproduce hydrologic dynamics of the reservoir. In addition, initial temperature calibration of the model was accomplished and output was capable of closely simulating relatively transitory vertical temperature dynamics of the system. Future efforts will include continued calibration for other water quality constituents.

OOLOGAH LAKE (WATER QUALITY CONTAMINANTS)

1. On four sampling dates toward the end of the study period, water samples were collected and analyzed for diesel range organics (DRO) total petroleum hydrocarbons (TPH). While detectable concentrations were present in 30% of these samples, concentrations were low and at or near low-level quantitation limits. The range of detected concentrations was 102 to 494 µg/l (parts per billion). Detection frequency and concentrations were similar to those observed over a more extended sampling period in 2000 (USACE 2001). A statistically significant, negative correlation was observed between lake-wide mean surface water TPH concentration and lake surface elevation during the initial year of study. Though sample numbers were limited for 2001, TPH detection frequency and average concentration were highest on 18 September 2001 when pool elevation was the lowest (637.56 feet) of the sampling dates.

2. Total and dissolved concentrations of a wide range of metals were measured in water samples from Oologah Lake through 19 June 2001 during this study. Concentrations of most toxic metals were generally below sample quantitation limits. In the initial year of study, an anomalous condition was observed on one sampling date when concentrations of cadmium and chromium exceeded raw water criteria in samples across the lake (USACE 2001). Similar conditions were not observed during this study period. Concentrations of chromium were below quantitation limits (0.025 mg/l) in all samples, and the maximum detected cadmium concentration was 0.006 mg/l. Consistent with results obtained during the initial year of study, metals concentrations did not appear to be at concentrations of concern in Oologah Lake waters.

OOLOGAH LAKE (SEDIMENTS)

1. Oologah Lake sediment samples were dominated by clay- and silt-sized grains. Longitudinal gradients of particle size were more typical of those common to reservoirs relative to results obtained in 2000. Though sample sizes for both years are limited, this more typical sedimentation pattern in 2001 may reflect the influence of lower inflow conditions on sediment sorting relative to that of higher flow events experienced in 2000.

2. Total organic carbon (TOC) concentrations reported for 2001 Oologah Lake sediment samples were extremely low and similar at all sampling sites. Sediment TOC concentrations were considerably lower than those measured at the same sites in 2000 and median concentrations were statistically distinct. Concentrations from both years were considerably lower and exhibited atypical distributional patterns relative to other Oklahoma reservoirs.

3. Extractable (diesel range) TPH concentrations were measured in Oologah Lake main pool sediments on 8 August 2001. Detectable concentrations were present in most samples but were low and near the quantitation limit. Concentrations ranged from <0.5 to 22.7 mg/Kg. When compared to results from August 2000 sampling from the main pool of Oologah Lake, concentrations were more variable among sites but median concentrations were not statistically different. Consistent with results of previous sediment investigations at Oologah Lake, detection of TPH in sediments was not associated with detectable concentrations of compound-specific organics (i.e., semi-volatile organics) or elevated metals concentrations that often accompany petroleum contamination.

4. Concentrations of many total metals in Oologah sediment samples collected 8 August 2001 exceeded typical “background” concentrations for freshwater sediments and northeastern Oklahoma surface soils. Concentrations were similar to those measured during the initial year of study. When evaluated using conservative screening-level criteria, no metals were excessively high or at levels posing significant potential risk to ecological receptors.

5. Concentrations of organochlorine pesticides, chlorinated herbicides, organophosphorus pesticides, and semi-volatile organics were below analytical quantitation limits in all sediment samples collected in 2001. Owing to detection of very low levels of atrazine in limited water samples collected in 2000 (USACE 2001), this compound was added to the analyte list for sediment samples collected in 2001. Concentrations were below the analytical quantitation limit (167 µg/Kg) in all samples.

WATERSHED LAND-USE AND MODELING

1. The Soil and Water Assessment Tool (SWAT), Version 2000 (Neitsch et al., 2001) was selected to process digital information to estimate average annual sediment yield, and nitrogen and phosphorus loading from the Oologah Lake watershed by generalized land use. Watershed modeling in the Oologah Lake watershed required spatially referenced digital data describing elevation, land use/cover, soil types and attributes, and weather.

2. The Oologah Lake watershed is defined by four 8-digit U.S. Geological Survey (USGS) hydrologic cataloging units (HUCs), including 11070101 (Upper Verdigris, Kansas), 11070102 (Fall, Kansas), 11070103 (Middle Verdigris, Kansas and Oklahoma) and 11070104 (Elk, Kansas). Each of these 8-digit HUCs is further subdivided into 11-digit HUCs that were used as the basis for subbasins modeled within SWAT.

3. The Oologah Lake watershed encompasses 1.1 million hectares in Oklahoma (19%) and Kansas (81%). Based on USGS (2000) National Land Cover Data, unmanaged grasslands account for 40% of the total basin area, managed pasture/hay land accounts for 30%, croplands 11%, forests 8%, and the remainder is distributed between other minor land uses.

4. Mean annual total, base, and surface runoff discharge estimates from the SWAT model were adjusted to match, as closely as possible, the estimates made from historical discharge data at selected gaging stations with unregulated flow. The calibrated SWAT model of the Oologah Lake watershed was run for a 45-year period based on the coincident period of record (1955 – 1999) of the available weather stations. Since calibration of sediment and nutrient export in the SWAT model of the Oologah Lake watershed has not yet been performed, reported values for these parameters should be viewed in relative, rather than absolute, terms. Results identify the relative magnitude of subbasin and land use contributions to sediment yield and nutrient export.

5. Simulated average annual basin-wide precipitation was 985.6 mm (38.8 inches) over the 45-year period with 229.6 mm/yr (9.04 in./yr) surface runoff. Runoff carried an estimated annual average 5.16 metric tons (t) of sediment per hectare per year, 4.80 kg/ha/yr organic nitrogen (as N), 1.26 kg/ha/yr nitrate (as N), 0.37 kg/ha/yr soluble phosphorus (as P), and 0.49 kg/ha/yr sediment-bound phosphorus (as P).

6. Subbasins with a higher percentage of agricultural land uses (row crops) tended to have higher average annual sediment export rates. A similar pattern existed for nutrient export in the Oologah Lake basin. Subbasins with a greater percentage of land area designated as crop tend to have higher average annual export rates. Predicted average annual sediment loading rates are highest for cropland (47.49 t/ha for row crop and 6.43 t/ha for close grown crop) and lowest for forests (average of 0.10 t/ha). Land uses accounting for the greatest percentage of total basin land area (excluding water), range (41.8%) and pasture (31.1%), have average annual export rates of 0.41 and 0.39 t/ha, respectively. Similarly, average annual nutrient export rates are highest for crop land (34.8 kg/ha total nitrogen and 3.3 kg/ha total phosphorus for row crop) in the watershed. Nutrient export rates for pasture land (4.2 kg/ha total nitrogen and 1.5 kg/ha total phosphorus) are significantly greater than range land (2.4 kg/ha total nitrogen and 0.1 kg/ha total phosphorus) due, in part, to the modeled assumption that these are managed pasture lands that receive fertilization from animal manure and commercial fertilizers.

7. Calculation of average annual loading in terms of kg (or t) per year by land use weights export rates by respective land use area. On an average annual basis, the model predicted that 93% of sediment exported from the basin originated from crop lands. Other land uses contributing significantly to sediment export based mostly on areal extent were pasture

(2.4%) and range (3.5%). Average annual nutrient export by land use follows a similar but slightly less dramatic pattern. Crop land uses account for 60% of total nitrogen export with pasture and range lands contributing 21.3% and 17.1%, respectively. Contributions to average annual total phosphorus export were dominated by pasture (54%) and crop (40%) land uses. Urban land use export rates for sediment and nutrients are generally higher than all land uses other than crop land, but they occupy a small areal fraction of the basin and thus contribute only a small fraction of total average annual sediment and nutrient loading.

8. Construction of the model, and its application, requires many assumptions. Limitations and significant sources of uncertainty must be identified. Errors in and scale of GIS data contribute significantly to uncertainty of modeled output. The functional modeling units of the SWAT model are combinations of specific land uses and soil types within hydrologically defined subbasins of the larger watershed. In order to reduce the complexity of the model, not every possible combination of land use and soil type is modeled. Weather data input into the model were collected at relatively few points in the basin. Rainfall can be highly variable, and the limited number of weather stations used in this study cannot effectively describe the actual variability. Pond morphometric data were estimated based on digital land use/cover data. In-stream and reservoir nutrient dynamics were not modeled. Calibration of sediment and nutrient export has not yet been performed. The simulation began before the operational dates of four of the five reservoirs in the watershed. Thus, annual average export rates and loading include periods when these reservoirs were not acting as sediment and nutrient traps in the basin. Point source nutrient inputs were not included in the present modeling effort.

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A CE-QUAL-W2 Reservoir Modeling

**OOLOGAH LAKE, OKLAHOMA, WATERSHED STUDY
YEAR 2 INTERIM REPORT OF FINDINGS:
OCTOBER 2000 – SEPTEMBER 2001**

1.0 INTRODUCTION AND OBJECTIVES

1.1 Introduction. This document provides a summary of data and findings obtained during a second year of investigation for the Oologah Lake, Oklahoma, Watershed Study. Overall, the project is designed as a multi-year investigation aimed at evaluating ecosystem degradation and resulting water quality threats in the Verdigris River Basin, Oklahoma and Kansas. A key component of the investigation is Oologah Lake, Oklahoma, a significant ecological resource and important water supply source for the city of Tulsa, Oklahoma, as well as a number of communities surrounding the lake. Field sampling and data collection for the project were initiated by the U.S. Army Corps of Engineers, Tulsa District (TD) during April 2000 and have continued to date. Study activities for the initial year of study were conducted under Congressional appropriation and confined to Oologah Lake itself and major tributary sites immediately adjacent to the reservoir. Data summaries and findings from this initial year were documented in an interim report prepared by the TD (USACE 2001).

The purpose of this report is to present data and findings from a second phase of investigations in the Verdigris River Watershed conducted under the Corps' Planning Assistance to States (PAS) Program. The project sponsor was the Oklahoma Water Resources Board (OWRB) with participation by the Tulsa Municipal Utilities Authority (TMUA), Tulsa, Oklahoma. In an effort to maintain project continuity, the report includes presentation and analysis of data collected during the period October 2000 to September 2001. If the study continues into additional future project phases, results of continuing data collection and analyses will be presented in subsequent reports.

1.2 Study Objectives. Objectives of this study were to continue data collection at Oologah Lake and its major tributaries, continue development and refinement of predictive tools for evaluating potential management strategies for ecosystem restoration and water quality

protection and improvement, and to expand the study into the extensive, 4,339-square-mile Verdigris River watershed above Oologah Dam. Accordingly, activities for this phase of study included the following major tasks: (1) collection of in-lake data at Oologah Lake in a manner similar to that established during the initial year of study; (2) continuous monitoring of key parameters, water sample collection and analysis, and load estimation for major tributaries to Oologah Lake; (3) continued refinement and calibration of a lake hydrodynamic and water quality model; and (4) quantification of land use and initial set-up and evaluation of a watershed model applicable to the Verdigris River Basin above Oologah Dam. Results from each of these areas of evaluation are detailed in this report.

A significant portion of this report is devoted not only to presentation of additional water quality data collected during the study period, but also to comparison of these findings to data collected during the initial year of study (described in USACE 2001). Hydrologic conditions in the Verdigris Basin were significantly different during the two periods of study, and analysis of resulting differences in water quality conditions provides insight into limnological dynamics of the system. Finally, a significant portion of this report is devoted to Verdigris River watershed land use characterization and watershed model development. These activities were a major work item for this phase of study and will be key components of future study in the basin.

1.3 Study Area. Detailed information regarding Oologah Lake project purposes, history, physical design features, general watershed land-use characteristics, and historical water quality were provided in the initial project report (USACE 2001). This document should be reviewed for general background information on the study area. As a result of this phase of study, land use classification in the Verdigris River Basin above Oologah Lake has been more definitively quantified. These findings are described in detail in Section 3.8 of this report.

2.0 METHODS

2.1 General. Detailed methodology for study tasks for the initial year of study at Oologah Lake (USACE 2001) was provided in the Project Work Plan and Quality Assurance Project Plan (QAPP) for the Oologah Lake Watershed Study (USACE 2000). Data quality management issues for the study were likewise addressed in this document. For the second year of study (Planning Assistance to States) described in this document, very similar methods and data quality management strategies were employed and described in a second, updated Project Work Plan / QAPP for this phase (“Project Work Plan / Quality Assurance Project Plan [QAPP], Oologah Lake, Oklahoma, Watershed Study, Fiscal Year 2001 [Year 2]”, May 2001). This section provides a brief review of sampling sites, actual sampling dates, and other specifics generally not provided in the project work plan.

2.2 Baseline In-Lake Sampling. A major focus of the second year of study was continued in-lake data collection for water quality problem identification and definition at Oologah Lake. In-lake data collection included sampling of both lake waters and sediments in accordance with established TD standard operating procedures (SOPs) (copies of which are provided in Appendix A of USACE 2000). Sampling details for each media are presented separately below.

2.2.1 Lake Water Quality Sampling. Water quality sampling at Oologah Lake was conducted by TD personnel at five sites along the thalweg from the upper end of the impoundment to Oologah Dam. These sites were identical to those used in initial sampling (USACE 2001); were spaced in an attempt to account for horizontal gradients common to large reservoirs; and facilitated data collection in areas commonly designated as riverine, transitional, and lacustrine zones (Thornton et al. 1981, 1990). Sampling site coordinates were initially established using an on-board global positioning system (GPS), and GPS equipment was used for navigation to these sites for subsequent sampling events. Sampling locations and coordinates are shown in Figure 2.2.1-1.

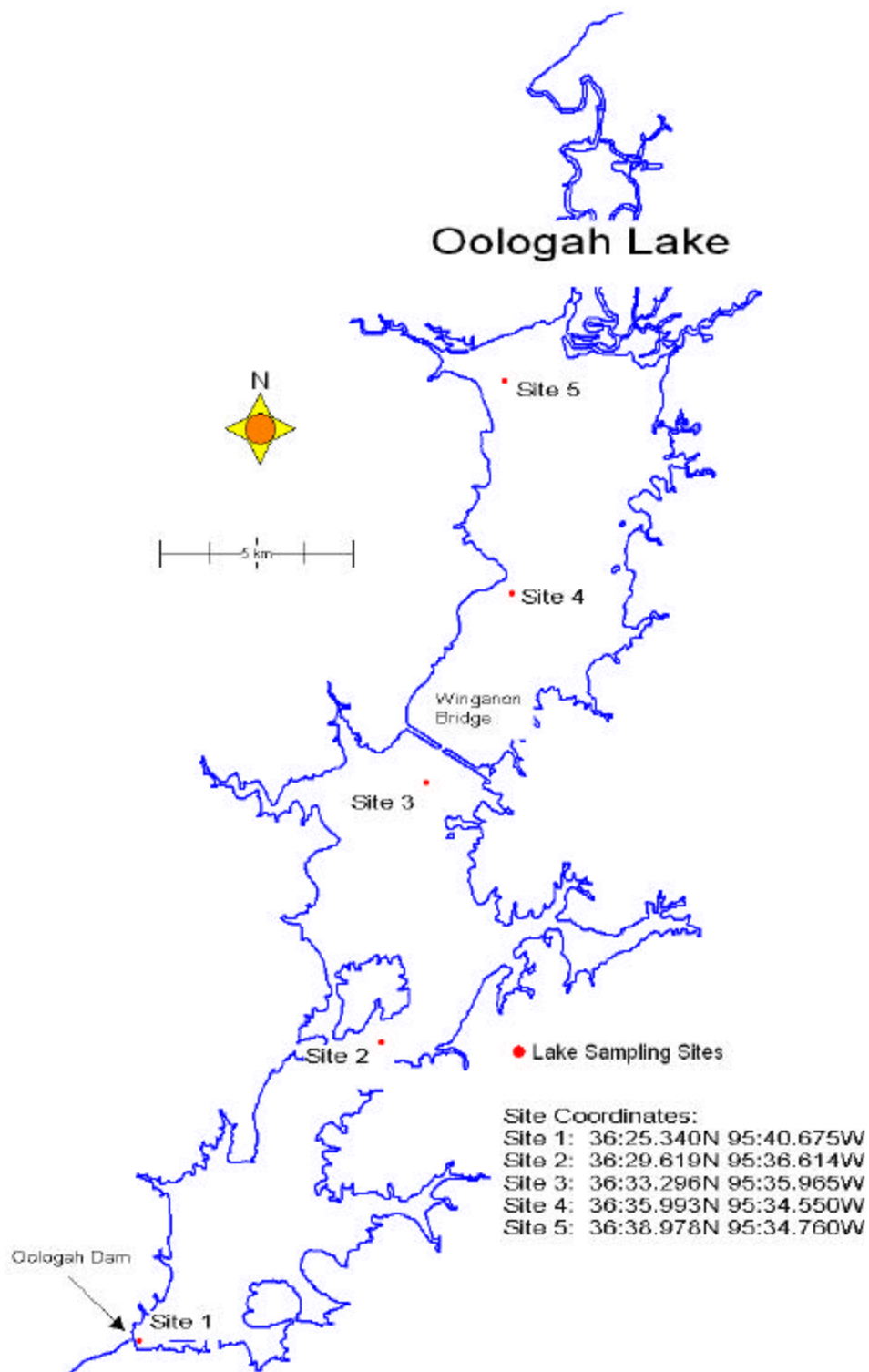


Figure 2.2.1-1
Oologah Lake water quality sampling sites.

In general, lake water quality sampling was conducted once during October and November 2000 but was not possible in December 2000 and January 2001 owing to ice cover during this period. Tributary sampling only was possible in February 2001 and lake sampling resumed again in mid-March 2001. Lake sampling was conducted once in April 2001 and was generally conducted biweekly throughout the remainder of the study period. Specific lake sampling dates were as follows:

24 October 2000
28 November 2000
13 March 2001
24 April 2001
15 May 2001
29 May 2001
19 June 2001
17 July 2001
31 July 2001
21 August 2001
4 September 2001
18 September 2001

Sampling was generally conducted between 0900 and 1500 hours. Sampling order at sites among sampling dates was varied to minimize time-dependent bias in sampling results.

Field data recorded at each site included both Secchi disk transparency and vertical profiles of photosynthetically active radiation (PAR). In addition, vertical profiles of water temperature, dissolved oxygen (DO), pH, conductivity, and nephelometric turbidity were recorded at the surface (0.1- and 0.5-meter [m] depth) and at 1-m depth intervals throughout the entire water column. Profile data were electronically logged and downloaded to a personal computer (PC) to minimize data transcription errors.

Water samples for physical, chemical, and biological laboratory analyses were collected at an approximate depth of 0.5 m at each site. The exception was the near dam site (Site 1, Figure 2.2.1-1) where samples were collected at depths of 0.5 m and 1 m above the sediments. Vertical profile data collected during this study generally substantiated previous findings that Oologah Lake rarely exhibits vertical thermal stratification and/or significant

oxygen depletion with depth, though some minor exceptions were noted at down-lake sites during a brief period of intense heating and drought (see results section). Accordingly, samples at depth were collected only at Site 1.

Analytical parameters initially employed for all Oologah Lake water samples as well as laboratory methods used for each constituent are included in Table 2.2.1-1. The list included a broad range of common limnological parameters including those important for water supply evaluation and those necessary to support the water quality modeling effort. As suspended solids were one area of focus for the study, the parameter list included a number of solids-related parameters as well as analysis for both total and dissolved fractions for important analytes. Beginning 17 July 2001, the parameter list was shortened to reduce study costs and streamline field sampling by eliminating parameters that were consistently below analytical detection limits, those that exhibited little spatial and temporal variability, and those for which data were being collected using field instruments (e.g., nephelometric turbidity). Accordingly, total alkalinity, total hardness, sulfate, total dissolved solids, settleable solids, volatile suspended solids, turbidity, BOD, and metals were eliminated. Owing to petroleum-related concerns and similar sampling during the initial year of study, sampling for extractable fraction total petroleum hydrocarbons (TPH) was continued beginning 21 August 2001. These samples were collected at an approximate depth of 0.1 m to include surface waters.

Water samples at each lake sampling site were collected at a depth of 0.5 m on all sampling dates for phytoplankton speciation and enumeration. Samples were transmitted to Dr. Robert A. Lynch of the University of Oklahoma Health Sciences Center for algal analyses. Algal analyses were intentionally delayed awaiting installation of state-of-the-art computerized analytical equipment capable of providing much-needed accurate measurement of algal bio-volume as well as speciation and enumeration. It was the decision of the study team not to delay release of this report pending receipt of these data. Phytoplankton data will therefore be provided as an addendum to this report once they are received. Samples for zooplankton analyses were collected on all sampling dates and preserved to facilitate long-term storage. To date, zooplankton samples (including those collected during the initial year of study) have been archived for future analysis, funding permitting.

Table 2.2.1-1. Analytical parameters and methods for lake water samples, Oologah Lake, Oklahoma.

Parameter	Analytical Method
Nutrients	
Total phosphorus	EPA 365.2
Total dissolved phosphorus	EPA 365.2
Dissolved ortho-phosphorus	EPA 365.2
Nitrate + Nitrite-N	EPA 353.2
Ammonia-N	EPA 350.1
Total Kjeldahl-N	EPA 351.2
Inorganics	
Total alkalinity	SM 2320-B
Total hardness	EPA 130.2
Chloride	EPA 325.3
Sulfate	EPA 375.2
Total dissolved solids	SM 2540-C
Solids	
Settleable solids	SM 2540-F
Total suspended solids	EPA 160.2
Volatile suspended solids	EPA 160.4
Turbidity	EPA 180.1
Metals	
Total iron	EPA 200.7
Dissolved iron	EPA 200.7
Total manganese	EPA 200.7
Dissolved manganese	EPA 200.7
Biological	
Phytoplankton speciation & enumeration	SM 10200-F
Zooplankton speciation & enumeration	Archived
Other	
Chlorophyll <i>a</i>	SM 10200-H(3)
Total organic carbon	SM 5310-C
Dissolved organic carbon	SM 5310-C
BOD (5-day)	EPA 405.1

In addition to collection of primary field samples, additional water samples were analyzed for quality assurance/quality control (QA/QC) purposes. This included one QC duplicate sample per trip that was analyzed for all chemical constituents for that sampling date. In addition, one field blank sample for all chemical parameters accompanied samples through the entire sampling, transportation, and analytical process on each lake sampling date. All samples were documented by signed chain-of-custody.

With the exception of chlorophyll *a*, TPH, and biological parameters (phytoplankton and zooplankton), analyses of water samples for all other parameters were conducted by the City of Tulsa Quality Assurance Laboratory, Tulsa, Oklahoma. The City of Tulsa QA lab performed data validation for all their analyses. Primary field samples and QC duplicates for TPH in water samples were analyzed by Environmental Testing and Consulting, Inc., Memphis, Tennessee. Quality assurance samples for TPH were analyzed by Test America, Inc., Nashville, Tennessee. Filtration and fluorometric analyses for chlorophyll *a* was conducted by the TD.

2.2.2 Lake Sediment Sampling. Limited sediment samples from Oologah Lake were collected 8 August 2001 and analyzed for a number of physical and chemical parameters. Samples were collected at a composited sediment depth of approximately 0-8 cm employing core sampling procedures described in Section 4 of the TD SOP manual (Appendix A of USACE 2000). Five primary field samples were collected at routine water quality sampling sites (Figure 2.2.1-1). In addition to primary field samples, triplicate samples were collected at one location for QA/QC analyses, and a rinsate blank was collected as a measure of sampling equipment cleaning efficiency.

Sediment samples were analyzed for all parameters listed in Table 2.2.2-1. Primary field sample analyses were conducted by Environmental Testing and Consulting, Inc., Memphis, Tennessee. Test America, Inc., Nashville, Tennessee, conducted analyses for QA samples. Particle size tests were conducted by Law Engineering and Environmental Services, Tulsa, Oklahoma.

**Table 2.2.2-1. Analytical parameters and methods for sediment samples,
Oologah Lake, Oklahoma**

Parameter	Analytical Method
Total phosphorus	365.3
Total nitrogen	352.1
Total organic carbon	415.1
Sulfate	300
Sulfide	376.2
Chloride	300
Total metals*	6010 / 7041 / 7060A / 7091 / 7131/ 7421 / 7470 & 7471 / 7740 / 7841
Chlorinated pesticides	SW-846 8081A
Chlorinated herbicides	SW-846 8151A
Organo-phosphorus pesticides	SW-846 8141A
Total petroleum hydrocarbons (extractable)	SW-846 8015M
Semi-volatile organics	SW-846 8270C
Particle size distribution (% sand, silt, clay)	ASTM D422
% solids	2540B

* Includes aluminum, antimony, arsenic, barium, beryllium, cadmium, calcium, chromium, copper, iron, lead, magnesium, manganese, mercury, nickel, potassium, selenium, silica, silver, sodium, thallium, zinc.

2.3 Major Tributary Gaging, Continuous Monitoring, and Water Quality Sampling. In an attempt to further define constituent loading and establish boundary conditions for the water quality modeling effort, continuous monitoring gaging stations employed during the initial year of study (USACE 2001) continued to be maintained on two major tributaries to Oologah Lake and in the Oologah Lake tailwaters. Upstream gages included existing U.S. Geological Survey (USGS) gage 07171000 located on the Verdigris River at State Highway 10, 2.8 miles east of Lenapah, Oklahoma (hereafter referred to as LEP02), which was upgraded with continuous recording water quality equipment for this study. In addition, a new gaging site was established during the initial year of study on Big Creek near Twin Bridges, approximately 4 miles east and 1 mile north of Childers, Oklahoma (hereafter referred to as CHBO2). Finally, stage recording and water quality instrumentation continued to be maintained at the discontinued USGS surface water station 07171400 in the Oologah Lake tailwaters (hereafter referred to as OOL02).

Locations of all gages and background information for these sites are provided in USACE 2000, 2001.

Instrumentation included at all gaging stations for the study included a continuous stage recorder and multi-probe water quality instrument capable of providing readings for water temperature, pH, dissolved oxygen, conductivity, and nephelometric turbidity. Data for these parameters were logged at 1-hour frequency, transferred via SDI-12 protocol to a data control platform (DCP), and uploaded via satellite to the TD Water Control Data System (WCDS). Data were archived by the TD and were available to the public real-time via the District's webpage (<http://www.swt-wc.usace.army.mil>). TD Hydrology and Hydraulics personnel accomplished periodic in-stream discharge measurements, gage maintenance, and regular instrument calibration. Continuous data collection was initiated on 1, 6, and 10 April 2000 at OOL02, LEP02, and CHB02, respectively, and continued as part of this study.

Water quality sample collection and analysis for load estimation were conducted at the two tributary sites listed above. Similar sampling was conducted at OOL02 as a measure of mass discharge from the impoundment. Periodic sampling at these locations generally, but not always, corresponded to lake sampling events and provided sampling data over a range of flow regimes and seasons. Samples were not collected during periods of zero discharge (particularly common at the tailwater site).

Water sample collection and analysis in Oologah Lake tributaries during high inflow periods was conducted during the initial year of study (USACE 2001) and proved to be important as a high proportion of loading to reservoirs typically occurs during such events. High flow sampling was likewise planned for this phase of study. However, the study period proved to be an extremely dry period, and no major inflow events occurred for Oologah Lake. Accordingly, sampling was limited to general time periods corresponding to lake sampling. Analytical parameters for all gaging site samples included those listed in Table 2.2.1-1 with the exception of TPH at LEP02 and CHB02 and zooplankton analyses at all sites. With the exception of chlorophyll, the City of Tulsa Quality Assurance Laboratory conducted analyses for

all tributary and tailwater samples. Sampling dates, corresponding flows, and results of these sampling efforts are thoroughly described in Section 3.2 of this report.

2.4 Bathymetric Mapping. Prior to this study, the most recent sediment survey for Oologah Lake was completed in 1977. In anticipation of the study, sedimentation survey data linking fathometer readings and GPS coordinates were collected by the TD at Oologah Lake in February, March, and June 2000. During this study period, the TD processed the data to produce an updated bathymetric map of the reservoir. Mapping data were used in estimating water volumes and depths necessary for establishing the computational grid for water quality modeling purposes. Results of these efforts and an updated contour map of the reservoir are provided in Section 3.1 of this report.

2.5 Reservoir Water Quality Modeling. A significant task for the overall Oologah Lake Watershed Study will be ultimate development of a means of evaluating watershed or in-lake management strategies on water quality in the reservoir. The overall goal of this task will be to provide a tool for simulating lake water quality response to a variety of possible management actions as a means of conducting “what if” type analyses. When properly applied, reservoir water quality modeling is particularly well suited for this purpose.

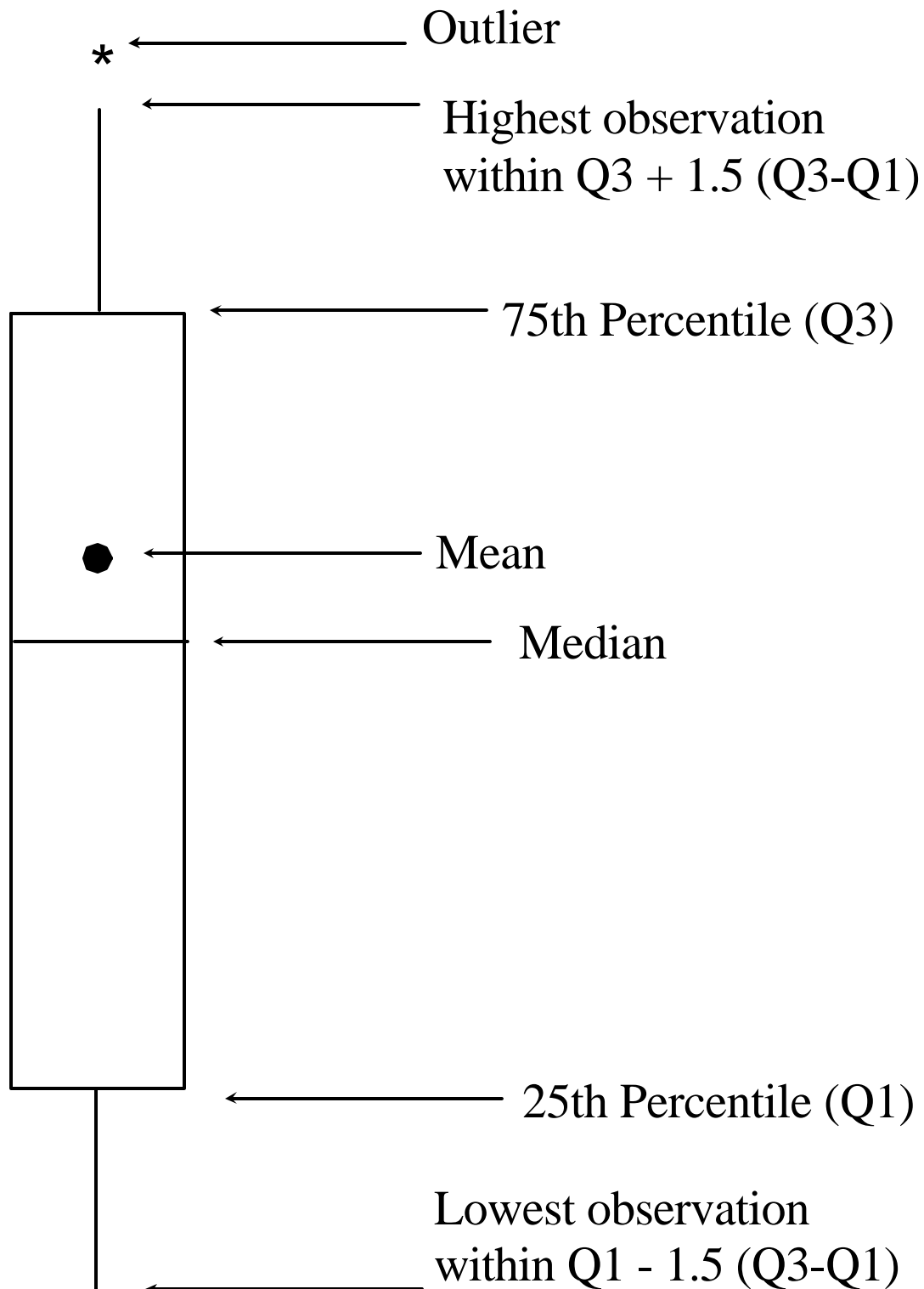
The reservoir model to be applied in this study is CE-QUAL-W2, a two-dimensional, longitudinal/vertical hydrodynamic and water quality model. Goals of the overall modeling exercise and its applicability to alternatives analysis are discussed in USACE (2000). For the initial study year, modeling efforts included initial model set-up and preliminary application by the U.S. Army Engineer Research and Development Center (ERDC), formerly the Waterways Experiment Station (WES), Vicksburg, Mississippi (USACE 2001). For this phase of the study, additional activities included further model refinement and calibration. Details of these activities and specific methodology are provided in Section 3.7 of this document.

2.6 Land Use Characterization and Watershed Modeling. Methods used for land use characterization and watershed modeling are thoroughly described along with results for these activities in Section 3.8 of this report.

2.7 Statistical Analyses. Statistical analyses were conducted using MINITAB 13 (Minitab, Inc. 2000). For hypothesis testing, differences were considered statistically significant at $\alpha \leq 0.05$ for gaging sites and for TPH and sediment analyses. Differences were considered statistically significant at $\alpha \leq 0.10$ for in-lake water quality samples to better account for ecological rather than statistical trends. Analyses were first performed to determine if the data deviated significantly from that of a normal distribution using the Anderson-Darling normality test. Once a normal or lognormal distribution was determined, analyses were performed to determine differences between sampling sites both spatially and temporally using tests appropriate for the distribution. Generally, differences among sampling sites and events were determined using analysis of variance (ANOVA) on ranked data. When differences among the medians were detected, Tukey's multiple comparison test was utilized to determine which medians were different. At Site 1, the statistical model used to determine differences between surface and bottom data was the t-test on ranked data. Spearman's rank correlation was generally used in correlation analyses.

A 'best subsets' linear regression analysis, within the statistical software package MINITAB (Minitab Inc. 2000), was used to determine least-squares relationships between selected constituents of the field-collected tributary water samples and correlated continuously monitored constituents. Calculated Pearson product moment correlation coefficients between selected field sample constituents and continuously monitored constituents were evaluated to identify potential surrogates.

"Box and whisker" plots were used for presentation of much of the data collected for this study. A generalized presentation of how these plots can be interpreted is provided below.



3.0 RESULTS

3.1 Bathymetric Mapping. Sediment survey data were collected by the USACE in February, March, and June 2000. This data consisted of approximately 1.2 million georeferenced data points with z-values corresponding to bottom surface elevation above sea level. The survey was performed by collecting data across the entire boat-accessible lake in primarily E-W transects 120 meters apart. This data was imported into Blackland GRASS GIS as point data, and a surface generation algorithm within the GIS program was performed to create the raster representation of the data shown in Figure 3.1-1.

The updated bathymetric map of Oologah Lake will eventually be compared to earlier sediment survey transects to estimate rates of sedimentation occurring in various portions of the lake and to estimate lake volume loss due to sedimentation.

3.2 Tributary Water Chemistry. Continuous (hourly) monitoring of tributaries to Oologah Lake (Verdigris River at Lenapah and Big Creek near Childers, Oklahoma) was continued through 2001. Continuously monitored parameters include precipitation, stage, discharge, water temperature, dissolved oxygen, pH, conductivity, and turbidity. A continuously-monitoring station was also continued at the tailwater location immediately below Oologah Dam. Field samples were collected at the tributaries in an attempt to sample a broad range of stream flow conditions. The distributions of water samples collected across the range of flows during the sampling period (April 2000 through September 2001) are shown for the Verdigris River (Lenapah) (Figure 3.2-2), and Big Creek (near Childers) (Figure 3.2-3). Indicated in the figures are the flows at which samples were collected, and the relative frequency of discharge occurrence. Field samples were collected, according to methods described in the Project Work Plan and Quality Assurance Project Plan (QAPP) for the Oologah Lake Watershed Study (USACE, 2000), and analyzed for a wide range of chemical, nutrient, and metals parameters.

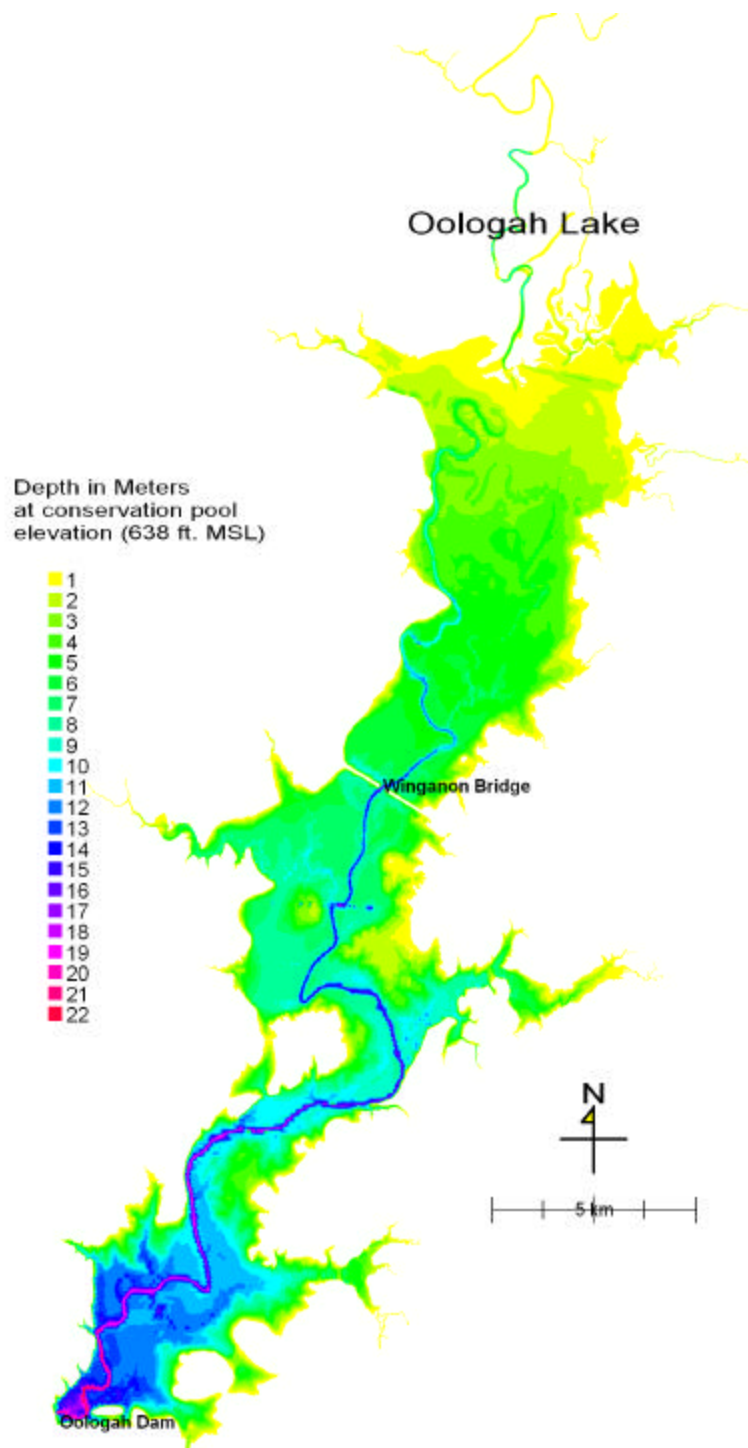


Figure 3.1-1
Oologah Lake bathymetry derived from year 2000 sediment survey data.

Graphic representations of continuous stream discharge and turbidity recorded at Verdigris River (Lenapah) and Big Creek (near Childers) from April 2000 through September 2001 are presented in Figure 3.2-4 and Figure 3.2-5, respectively. A close correlation between rising limbs of discharge during storm runoff events and increased turbidity measurements are evident for each site.

The analysis of tributary data was limited by the number of field samples collected at each of the tributary sites. For the period April 2000 through September 2001, 28 samples were collected from Verdigris River (Lenapah) and 22 from Big Creek (near Childers). Periodic absence of flow in Big Creek limited the opportunities for sampling at that site. Statistical summaries of laboratory-analyzed constituents in field-collected samples are presented in Table 3.2-1 and Table 3.2-2 for the Verdigris River (Lenapah) and Big Creek (near Childers), respectively. The tables summarize data from April through September 2000, 2001, and all data combined. Two sample t-tests indicated statistically significant ($p < 0.05$) differences between 2000 and 2001 means for alkalinity and hardness (year 2000 means $<$ year 2001 means), total Kjeldahl nitrogen, nitrate + nitrite, total phosphorus, dissolved phosphorus, dissolved ortho-phosphorus, and turbidity (year 2000 means $>$ year 2001 means) at the Verdigris River (Lenapah). Continuously monitored data at this site were used to determine flows at sampling times, and mean discharge for the 2000 comparison period was significantly different from the 2001 mean discharge (year 2000 $>$ year 2001).

Fewer significant differences between constituent means for the 2000 and 2001 comparison periods at Big Creek (near Childers) were noted ($p < 0.05$ for alkalinity, dissolved Kjeldahl nitrogen, and turbidity), but the same general pattern was evident. Alkalinity, total dissolved solids, and hardness means were higher in the 2001 sampling period, and most other constituent means were lower for the 2001 sampling period. Mean discharge at sampling time was greater in 2000.

Field data collected from the Verdigris River (below Oologah Dam) were also limited in number due to a lack of water releases from the reservoir through significant portions of the period. Laboratory analyses of Verdigris River (below Oologah Dam) sampled data are

summarized in Table 3.2-3. Constituent means are similar for comparison periods in 2000 and 2001.

Results of metals analysis at Verdigris River (Lenapah), Big Creek (near Childers), and Verdigris River (below Oologah Dam) are presented in Table 3.2-4. Samples were collected at each site on one date (12 March 2001 for Verdigris River at Lenapah and Big Creek, and 13 March 2001 for Verdigris River below Oologah Dam). Most metals were present at or below the practicable quantitation limits. Those metals that were present in measurable quantities include aluminum, barium, calcium, iron, magnesium, manganese, potassium, silicon, and sodium.

Statistical summaries of continuously monitored constituents at Verdigris River (Lenapah), Big Creek (near Childers), and Verdigris River (below Oologah Dam) are presented in Table 3.2-5, Table 3.2-6, and Table 3.2-7, respectively. Mean constituent values are similar between comparison periods in 2000 and 2001 at all three sites.

Concentrations of constituents in surface water are often strongly related to other constituent concentrations and additional environmental factors (Christensen, et al., 2000). Regression equations that are based on surrogate physical properties measured in real time can be useful in estimating those constituents not measured in real time. A ‘best subsets’ linear regression analysis, within the statistical software package MINITAB (Minitab Inc., 2000), was again used to determine least-squares relationships between selected constituents of the field collected tributary water samples and correlated continuously monitored constituents for the expanded sampling period. Calculated Pearson product moment correlation coefficients between selected field sample constituents and continuously monitored constituents were evaluated to identify potential surrogates. For some developed relationships, the independent variable(s), dependent variable(s), or both, were log transformed to develop linear equations. Relationships were evaluated using mean square error (MSE) and the coefficient of determination (R^2). Relative percentage differences (RPDs) between measured and estimated constituent concentrations were also calculated to evaluate each developed relationship. The developed

relationships were also used to compare selected measured and estimated constituent loading at the tributary sites.

Resulting regression equations at each tributary site are presented in Table 3.2-8. Regression relationships were developed for alkalinity, hardness, total dissolved solids, total suspended solids, chloride, sulfate, total organic carbon, total nitrogen, total Kjeldahl nitrogen, total phosphorus, dissolved phosphorus, and dissolved ortho-phosphorus at both Verdigris River (Lenapah) and Big Creek (near Childers). At Verdigris River (Lenapah), 10 of the 12 relationships had R^2 values greater than 0.70. Equations developed for alkalinity, hardness, total dissolved solids, total suspended solids, chloride, total nitrogen, total Kjeldahl nitrogen, and total phosphorus had R^2 values above 0.80. Total organic carbon and dissolved ortho-phosphorus relationships had the lowest R^2 values at this site (0.58 and 0.63, respectively).

At Big Creek (near Childers), 9 of the 12 relationships had R^2 values greater than 0.70. Equations developed for alkalinity, hardness, total dissolved solids, total organic carbon, total phosphorus, dissolved phosphorus, and dissolved ortho-phosphorus had R^2 values above 0.80. Lowest coefficients of determination at this site were for relationships developed for sulfate (0.27), total nitrogen (0.50), and chloride (0.67).

The regression equations for estimates of each of the constituents at each site were used to estimate concentrations that were plotted against measured constituent concentrations (Figure 3.2-6 through Figure 3.2-17 for Verdigris River (Lenapah), and Figure 3.2-18 through Figure 3.2-29 for Big Creek). Relative percentage differences (RPDs) between measured and estimated concentrations were calculated. The median RPD was calculated and reported for each relationship (Table 3.2-9). At Verdigris River, (Lenapah) four constituents (alkalinity, hardness, total dissolved solids, and total organic carbon), had calculated median RPDs of less than 10%, with the lowest being 3.37% for hardness. The highest median RPD at Verdigris River (Lenapah) was for the sulfate relationship (72%). At Big Creek (near Childers), three constituent relationships (hardness, total dissolved solids, and dissolved ortho-phosphorus) had median RPDs less than 10%. Relationships developed for alkalinity, total organic carbon, total

phosphorus, and dissolved phosphorus had median RPDs less than 20%. The highest calculated median RPD at the Big Creek site was 177% for the total nitrogen relationship.

Nutrient and solids loading estimates were also compared to ‘measured’ loads. Accurate estimates of constituent loading necessarily require observations throughout individual storm events since constituents are delivered to the stream at varying rates in the rising and falling limbs of each individual storm hydrograph. Measured instantaneous loads of total suspended solids, total nitrogen, and total phosphorus were calculated from measured concentrations and corresponding continuous discharge measurements and reported in units of kg/d. TN was not analyzed directly, but rather estimated as the sum of total Kjeldahl nitrogen and nitrate + nitrite. Estimated concentrations were calculated using the regression equations reported in Table 3.2-8 and multiplied by corresponding instantaneous discharge, and a conversion factor, to get units of kg/d. Tabular results of loading estimates for both Verdigris River (Lenapah) and Big Creek (near Childers) are presented in Table 3.2-10. The relatively few measured observations of nutrient and solids concentrations at the tributary sites do not provide enough information for an accurate estimation of individual storm event or long-term loading. Regression estimates based on continuously monitored surrogates may provide a better picture of delivered loads. At Verdigris River (Lenapah), estimated median loads for total suspended solids, total nitrogen, and total phosphorus were 41,230 kg/d, 2,010 kg/d, and 100 kg/d, respectively. At Big Creek (near Childers), estimated median loads for total suspended solids, total nitrogen, and total phosphorus were 1,070 kg/d, 30 kg/d, and <10 kg/d, respectively.

Figure 3.2-30 through Figure 3.2-35 graphically compare measured and estimated loads of total suspended solids, total nitrogen, and total phosphorus for Verdigris River (Lenapah) and Big Creek (near Childers) across the entire sampling period.

Table 3.2-1. Summary statistics for water quality parameters at the Verdigris River (Lenapah) for April through September 2000, 2001, and April 2000 through September 2001.

Constituent	Units	Mean	Median	St. Dev.	Min.	Max.	# > DL	# BDL	N total
April through September 2000									
Alkalinity, Total	mg/l	107.81	103.50	37.79	51.00	168.00	16	0	16
BOD (5) Day	mg/l	4.31	3.80	1.84	<2.0	6.80	9	7	16
Carbon, Organic, Dissolved	mg/l	5.02	4.85	1.17	3.30	8.00	16	0	16
Carbon, Organic, Total	mg/l	5.34	5.15	1.25	3.30	7.70	16	0	16
Chloride, Total	mg/l	16.09	14.00	12.15	5.00	55.70	16	0	16
Chlorophyll <i>a</i>	µg/l	10.00	8.37	11.65	2.00	50.45	16	0	16
Hardness, Total	mg/l	127.69	124.00	40.95	66.40	192.00	16	0	16
Nitrogen, Ammonia (as N)	mg/l	2.47	0.10	4.41	<0.05	10.00	8	8	16
Nitrogen, Kjeldahl, Dissolved (as N)	mg/l	0.82	0.60	0.50	<0.3	2.11	11	5	16
Nitrogen, Kjeldahl, Total (as N)	mg/l	1.97	1.71	1.23	<0.03	4.18	15	1	16
Nitrogen, Nitrite (as N)	mg/l	-	-	-	<0.02	-	0	1	1
Nitrogen, Nitrate (as N)	mg/l	0.03	0.03	-	0.03	0.03	1	0	1
Nitrogen, Nitrate-Nitrite (as N)	mg/l	0.59	0.58	0.28	<0.3	1.27	14	2	16
Ortho-Phosphorus, Dissolved (as P)	mg/l	0.08	0.08	0.03	0.04	0.13	16	0	16
Phosphorus, Dissolved, Total (as P)	mg/l	0.08	0.09	0.03	0.03	0.14	16	0	16
Phosphorus, Total (as P)	mg/l	0.46	0.35	0.44	0.02	1.71	16	0	16
Solids Settleable	ml/l	0.69	0.30	0.64	<0.1	2.00	11	5	16
Solids, Total Dissolved	mg/l	212.88	219.50	40.00	125.00	273.00	16	0	16
Solids, Total Suspended	ml/l	390.82	193.00	417.33	16.00	1,160.00	16	0	16
Solids, Volatile	mg/l	38.23	26.00	35.89	4.30	110.00	16	0	16
Solids, Volatile Suspended	mg/l	-	-	-	-	-	-	-	0
Sulfate	mg/l	-	-	-	-	-	-	-	0
Sulfate, Dissolved	mg/l	44.98	24.50	43.38	3.70	130.00	16	0	16
Turbidity	NTU	312.17	241.00	272.15	12.00	706.00	16	0	16
April through September 2001									
Alkalinity, Total	mg/l	133.33	135.00	17.51	110.00	160.00	6	0	6
BOD (5) Day	mg/l	2.45	2.45	0.49	<2.0	2.80	2	4	6
Carbon, Organic, Dissolved	mg/l	4.50	4.30	0.79	3.60	5.60	7	0	7
Carbon, Organic, Total	mg/l	4.93	4.30	1.36	3.70	7.30	7	0	7
Chloride, Total	mg/l	23.86	22.00	8.63	13.00	38.00	7	0	7
Chlorophyll <i>a</i>	µg/l	18.25	15.15	12.43	4.70	38.30	6	0	6
Hardness, Total	mg/l	168.33	165.00	17.22	150.00	200.00	6	0	6
Nitrogen, Ammonia (as N)	mg/l	-	-	-	<0.05	-	0	7	7
Nitrogen, Kjeldahl, Dissolved (as N)	mg/l	0.47	0.42	0.18	<0.3	0.65	5	2	7
Nitrogen, Kjeldahl, Total (as N)	mg/l	0.71	0.76	0.22	0.32	0.93	7	0	7
Nitrogen, Nitrite (as N)	mg/l	0.04	0.04	-	<0.02	0.04	1	6	7
Nitrogen, Nitrate (as N)	mg/l	0.32	0.32	0.20	0.04	0.61	7	0	7
Nitrogen, Nitrate-Nitrite (as N)	mg/l	0.33	0.32	0.21	0.04	0.64	7	0	7
Ortho-Phosphorus, Dissolved (as P)	mg/l	0.04	0.03	0.03	0.01	0.10	7	0	7
Phosphorus, Dissolved, Total (as P)	mg/l	0.04	0.04	0.02	0.03	0.07	7	0	7
Phosphorus, Total (as P)	mg/l	0.11	0.09	0.06	0.06	0.23	7	0	7
Solids Settleable	ml/l	-	-	-	<0.1	-	0	6	6
Solids, Total Dissolved	mg/l	248.33	260.00	46.22	170.00	310.00	6	0	6
Solids, Total Suspended	ml/l	121.29	38.00	187.17	21.00	540.00	7	0	7
Solids, Volatile	mg/l	-	-	-	-	-	-	-	0
Solids, Volatile Suspended	mg/l	8.30	6.95	3.20	5.50	14.00	6	0	6
Sulfate	mg/l	17.46	14.70	7.50	<3.9	26.00	5	1	6
Sulfate, Dissolved	mg/l	-	-	-	-	-	-	-	0
Turbidity	NTU	47.67	31.50	33.74	22.00	110.00	6	0	6

Table 3.2-1 (Continued)

Constituent	Units	Mean	Median	St. Dev.	Min.	Max.	# > DL	# BDL	N total
April 2000 through September 2001									
Alkalinity, Total	mg/l	116.04	120.00	36.11	51.00	180.00	27	0	27
BOD(5) Day	mg/l	4.01	3.65	1.62	<2.0	6.80	16	11	27
Carbon, Organic, Dissolved	mg/l	5.89	5.10	4.49	3.30	28.00	28	0	28
Carbon, Organic, Total	mg/l	5.46	5.30	1.35	<3.0	7.70	27	1	28
Chloride, Total	mg/l	20.51	18.00	12.60	5.00	55.70	28	0	28
Chlorophyll <i>a</i>	µg/l	11.67	8.82	11.79	2.00	50.45	24	0	24
Hardness, Total	mg/l	139.85	150.00	38.50	66.40	200.00	27	0	27
Nitrogen, Ammonia (as N)	mg/l	2.02	0.13	4.00	<0.05	10.00	10	18	28
Nitrogen, Kjeldahl, Dissolved (as N)	mg/l	0.77	0.65	0.42	<0.3	2.11	20	8	28
Nitrogen, Kjeldahl, Total (as N)	mg/l	1.58	1.30	1.11	<0.03	4.18	27	1	28
Nitrogen, Nitrite (as N)	mg/l	0.04	0.04	-	<0.02	0.04	1	11	12
Nitrogen, Nitrate (as N)	mg/l	0.37	0.28	0.39	0.03	1.30	13	0	13
Nitrogen, Nitrate-Nitrite (as N)	mg/l	0.50	0.42	0.34	<0.3	1.30	26	2	28
Ortho-Phosphorus, Dissolved (as P)	mg/l	0.07	0.07	0.04	<0.008	0.19	27	1	28
Phosphorus, Dissolved, Total (as P)	mg/l	0.08	0.06	0.05	0.03	0.22	28	0	28
Phosphorus, Total (as P)	mg/l	0.34	0.16	0.39	0.02	1.71	28	0	28
Solids Settleable	ml/l	0.63	0.30	0.61	<0.1	2.00	13	14	27
Solids, Total Dissolved	mg/l	226.07	230.00	43.05	125.00	310.00	27	0	27
Solids, Total Suspended	ml/l	282.72	107.00	355.91	10.00	1,160.00	28	0	28
Solids, Volatile	mg/l	35.92	24.00	34.36	4.30	110.00	19	0	19
Solids, Volatile Suspended	mg/l	12.96	8.00	14.12	<4.0	50.00	9	1	10
Sulfate	mg/l	37.42	26.00	40.12	<3.9	140.00	9	1	10
Sulfate, Dissolved	mg/l	48.91	28.00	45.47	3.70	140.00	19	0	19
Turbidity	NTU	233.40	85.60	254.51	7.70	706.00	27	0	27

Table 3.2-2. Summary statistics for water quality parameters at the Big Creek (near Childers) for April through September 2000, 2001, and April 2000 through September 2001.

Constituent	Units	Mean	Median	St. Dev.	Min.	Max.	# > DL	# BDL	N total
April through September 2000									
Alkalinity, Total	mg/l	97.58	72.50	54.70	38.00	194.00	12	0	12
BOD (5) Day	mg/l	3.80	3.30	1.51	<2.0	6.20	9	3	12
Carbon, Organic, Dissolved	mg/l	5.31	6.00	2.34	2.00	8.60	12	0	12
Carbon, Organic, Total	mg/l	6.05	6.55	2.87	2.30	9.90	12	0	12
Chloride, Total	mg/l	4.70	5.00	2.67	<1.0	9.80	11	1	12
Chlorophyll <i>a</i>	µg/l	5.92	4.69	5.00	0.65	16.80	12	0	12
Hardness, Total	mg/l	124.17	109.00	63.26	46.00	228.00	12	0	12
Nitrogen, Ammonia (as N)	mg/l	0.10	0.11	0.02	<0.06	0.12	4	8	12
Nitrogen, Kjeldahl, Dissolved (as N)	mg/l	0.74	0.80	0.23	<0.3	1.11	8	4	12
Nitrogen, Kjeldahl, Total (as N)	mg/l	0.90	0.87	0.63	<0.03	1.96	10	2	12
Nitrogen, Nitrite (as N)	mg/l	-	-	-	-	-	-	-	0
Nitrogen, Nitrate (as N)	mg/l	-	-	-	-	-	-	-	0
Nitrogen, Nitrate-Nitrite (as N)	mg/l	0.29	0.25	0.13	<0.02	0.48	8	4	12
Ortho-Phosphorus, Dissolved (as P)	mg/l	0.04	0.04	0.03	<0.01	0.08	12	0	12
Phosphorus, Dissolved, Total (as P)	mg/l	0.06	0.07	0.04	<0.005	0.11	10	2	12
Phosphorus, Total (as P)	mg/l	0.27	0.19	0.31	0.03	1.06	12	0	12
Solids Settleable	ml/l	0.41	0.20	0.50	<0.10	1.50	7	5	12
Solids, Total Dissolved	mg/l	176.60	180.50	51.34	96.20	268.00	12	0	12
Solids, Total Suspended	ml/l	277.54	116.00	392.19	<4.0	1,270.00	11	1	12
Solids, Volatile	mg/l	89.04	28.00	145.35	<4.0	432.00	8	4	12
Solids, Volatile Suspended	mg/l	-	-	-	-	-	-	-	0
Sulfate	mg/l	-	-	-	-	-	-	-	0
Sulfate, Dissolved	mg/l	17.92	12.50	14.12	2.90	50.00	12	0	12
Turbidity	NTU	115.64	114.35	95.59	5.52	259.00	12	0	12
April through September 2001									
Alkalinity, Total	mg/l	141.67	135.00	27.14	110.00	190.00	6	0	6
BOD (5) Day	mg/l	2.50	2.50	-	<2.0	2.50	1	5	6
Carbon, Organic, Dissolved	mg/l	4.19	4.00	1.49	2.50	6.80	7	0	7
Carbon, Organic, Total	mg/l	4.81	4.10	1.96	2.60	7.70	7	0	7
Chloride, Total	mg/l	6.10	6.10	1.51	4.40	8.60	7	0	7
Chlorophyll <i>a</i>	µg/l	9.65	9.35	3.63	5.70	13.60	6	0	6
Hardness, Total	mg/l	166.67	155.00	31.41	130.00	210.00	6	0	6
Nitrogen, Ammonia (as N)	mg/l	0.12	0.12	-	<0.06	0.12	1	6	7
Nitrogen, Kjeldahl, Dissolved (as N)	mg/l	0.49	0.54	0.13	<0.3	0.58	4	3	7
Nitrogen, Kjeldahl, Total (as N)	mg/l	0.49	0.48	0.17	<0.03	0.73	6	1	7
Nitrogen, Nitrite (as N)	mg/l	-	-	-	<0.02	-	0	7	7
Nitrogen, Nitrate (as N)	mg/l	0.23	0.11	0.25	<0.02	0.68	5	2	7
Nitrogen, Nitrate-Nitrite (as N)	mg/l	0.23	0.11	0.25	<0.02	0.68	5	2	7
Ortho-Phosphorus, Dissolved (as P)	mg/l	0.03	0.03	0.03	<0.01	0.06	3	4	7
Phosphorus, Dissolved, Total (as P)	mg/l	0.03	0.02	0.03	<0.005	0.09	6	1	7
Phosphorus, Total (as P)	mg/l	0.07	0.04	0.09	0.01	0.27	7	0	7
Solids Settleable	ml/l	-	-	-	<0.10	-	0	6	6
Solids, Total Dissolved	mg/l	215.00	210.00	27.39	190.00	260.00	6	0	6
Solids, Total Suspended	ml/l	20.10	10.00	21.56	6.90	68.00	7	0	7
Solids, Volatile	mg/l	-	-	-	-	-	-	-	0
Solids, Volatile Suspended	mg/l	5.60	5.60	1.70	<4.0	6.80	2	4	6
Sulfate	mg/l	12.32	9.58	7.32	5.27	26.00	6	0	6
Sulfate, Dissolved	mg/l	-	-	-	-	-	-	-	0
Turbidity	NTU	11.53	7.85	6.62	6.30	21.00	6	0	6

Table 3.2-2 (Continued)

Constituent	Units	Mean	Median	St. Dev.	Min.	Max.	# > DL	# BDL	N total
April 2000 through September 2001									
Alkalinity, Total	mg/l	116.33	130.00	48.27	38.00	194.00	21	0	21
BOD(5) Day	mg/l	3.70	3.05	1.46	<2.0	6.20	12	9	21
Carbon, Organic, Dissolved	mg/l	4.90	4.65	1.97	2.00	8.60	22	0	22
Carbon, Organic, Total	mg/l	5.55	5.55	2.45	2.30	9.90	22	0	22
Chloride, Total	mg/l	5.50	6.00	2.30	<1.0	9.80	21	1	22
Chlorophyll <i>a</i>	µg/l	6.68	5.35	4.81	0.65	16.80	20	0	20
Hardness, Total	mg/l	140.52	150.00	53.31	46.00	228.00	21	0	21
Nitrogen, Ammonia (as N)	mg/l	0.11	0.12	0.02	<0.06	0.15	6	16	22
Nitrogen, Kjeldahl, Dissolved (as N)	mg/l	0.68	0.58	0.28	<0.3	1.30	15	7	22
Nitrogen, Kjeldahl, Total (as N)	mg/l	0.72	0.62	0.50	<0.03	1.96	19	3	22
Nitrogen, Nitrite (as N)	mg/l	-	-	-	<0.02	-	0	9	9
Nitrogen, Nitrate (as N)	mg/l	0.36	0.24	0.32	<0.02	0.96	8	2	10
Nitrogen, Nitrate-Nitrite (as N)	mg/l	0.32	0.25	0.24	<0.02	0.98	16	6	22
Ortho-Phosphorus, Dissolved (as P)	mg/l	0.04	0.05	0.03	<0.01	0.08	17	5	22
Phosphorus, Dissolved, Total (as P)	mg/l	0.05	0.04	0.04	<0.005	0.11	19	3	22
Phosphorus, Total (as P)	mg/l	0.18	0.06	0.25	0.01	1.06	22	0	22
Solids Settleable	ml/l	0.41	0.20	0.50	<0.10	1.50	7	14	21
Solids, Total Dissolved	mg/l	192.39	196.00	45.34	96.20	268.00	21	0	21
Solids, Total Suspended	ml/l	155.41	19.10	307.05	<4.0	1,270.00	21	1	22
Solids, Volatile	mg/l	79.84	24.00	138.73	<4.0	432.00	9	5	14
Solids, Volatile Suspended	mg/l	5.07	4.40	1.51	<4.0	6.80	3	4	7
Sulfate	mg/l	13.22	9.87	7.09	5.27	26.00	7	0	7
Sulfate, Dissolved	mg/l	17.31	12.50	13.21	2.90	50.00	14	0	14
Turbidity	NTU	73.51	23.00	86.92	5.52	259.00	21	0	21

Table 3.2-3. Summary statistics for water quality parameters for the Verdigris River (below Oologah Dam) for April through September 2000, 2001, and April 2000 through September 2001.

Constituent	Units	Mean	Median	St. Dev.	Min.	Max.	# > DL	# BDL	N total
April through September 2000									
Alkalinity, Total	mg/l	101.00	98.00	8.16	95.00	113.00	4	1	5
BOD (5) Day	mg/l	-	-	-	0.00	-	0	5	5
Carbon, Organic, Dissolved	mg/l	3.90	3.80	0.17	3.80	4.20	5	0	5
Carbon, Organic, Total	mg/l	4.06	4.00	0.19	3.80	4.30	5	0	5
Chloride, Total	mg/l	12.10	12.00	3.51	7.50	16.00	5	0	5
Chlorophyll <i>a</i>	µg/l	2.76	1.40	2.36	1.00	6.40	5	0	5
Hardness, Total	mg/l	153.60	158.00	13.20	132.00	167.00	5	0	5
Nitrogen, Ammonia (as N)	mg/l	-	-	-	0.00	-	0	5	5
Nitrogen, Kjeldahl, Dissolved (as N)	mg/l	0.47	0.47	0.13	0.34	0.61	3	2	5
Nitrogen, Kjeldahl, Total (as N)	mg/l	0.38	0.41	0.11	0.23	0.48	4	1	5
Nitrogen, Nitrite (as N)	mg/l	-	-	-	-	-	-	-	0
Nitrogen, Nitrate (as N)	mg/l	-	-	-	-	-	-	-	0
Nitrogen, Nitrate-Nitrite (as N)	mg/l	0.81	0.53	0.69	0.36	1.84	4	1	5
Ortho-Phosphorus, Dissolved (as P)	mg/l	0.05	0.05	0.02	0.03	0.07	5	0	5
Phosphorus, Dissolved, Total (as P)	mg/l	0.05	0.05	0.01	0.03	0.06	5	0	5
Phosphorus, Total (as P)	mg/l	0.08	0.07	0.02	0.07	0.11	4	1	5
Solids Settleable	ml/l	-	-	-	0.00	-	0	5	5
Solids, Total Dissolved	mg/l	255.75	254.00	11.50	245.00	270.00	4	1	5
Solids, Total Suspended	ml/l	52.92	9.67	97.36	5.92	227.00	5	0	5
Solids, Volatile	mg/l	19.80	19.80	19.09	6.30	33.30	2	3	5
Solids, Volatile Suspended	mg/l	-	-	-	-	-	-	-	0
Sulfate	mg/l	-	-	-	-	-	-	-	0
Sulfate, Dissolved	mg/l	79.25	48.00	67.43	41.00	180.00	4	1	5
Turbidity	NTU	34.68	36.05	16.80	13.20	53.40	4	1	5
April through September 2001									
Alkalinity, Total	mg/l	116.50	99.50	35.69	97.00	170.00	4	0	4
BOD (5) Day	mg/l	-	-	-	0.00	-	0	4	4
Carbon, Organic, Dissolved	mg/l	4.16	4.10	0.36	3.80	4.70	5	0	5
Carbon, Organic, Total	mg/l	4.16	4.10	0.53	3.50	4.90	5	0	5
Chloride, Total	mg/l	13.40	13.00	1.82	11.00	16.00	5	0	5
Chlorophyll <i>a</i>	µg/l	1.75	1.60	0.52	1.30	2.50	4	0	4
Hardness, Total	mg/l	145.00	145.00	12.91	130.00	160.00	4	0	4
Nitrogen, Ammonia (as N)	mg/l	0.14	0.16	0.08	0.05	0.26	5	0	5
Nitrogen, Kjeldahl, Dissolved (as N)	mg/l	0.54	0.57	0.19	0.23	0.72	5	0	5
Nitrogen, Kjeldahl, Total (as N)	mg/l	0.63	0.58	0.23	0.32	0.89	5	0	5
Nitrogen, Nitrite (as N)	mg/l	0.03	0.03	0.01	0.02	0.04	2	3	5
Nitrogen, Nitrate (as N)	mg/l	0.78	0.88	0.45	0.06	1.20	5	0	5
Nitrogen, Nitrate-Nitrite (as N)	mg/l	0.78	0.88	0.45	0.07	1.20	5	0	5
Ortho-Phosphorus, Dissolved (as P)	mg/l	0.09	0.08	0.03	0.06	0.14	5	0	5
Phosphorus, Dissolved, Total (as P)	mg/l	0.09	0.08	0.04	0.06	0.16	5	0	5
Phosphorus, Total (as P)	mg/l	0.12	0.10	0.04	0.07	0.17	5	0	5
Solids Settleable	ml/l	-	-	-	0.00	-	0	4	4
Solids, Total Dissolved	mg/l	252.50	245.00	35.94	220.00	300.00	4	0	4
Solids, Total Suspended	ml/l	18.70	17.00	9.62	7.50	34.00	5	0	5
Solids, Volatile	mg/l	-	-	-	-	-	-	-	0
Solids, Volatile Suspended	mg/l	6.00	6.00	-	6.00	6.00	1	3	4
Sulfate	mg/l	40.88	42.05	8.64	29.70	49.70	4	0	4
Sulfate, Dissolved	mg/l	-	-	-	-	-	-	-	0
Turbidity	NTU	51.25	40.00	25.29	36.00	89.00	4	0	4

Table 3.2-3 (Continued)

Constituent	Units	Mean	Median	St. Dev.	Min.	Max.	# > DL	# BDL	N total
April 2000 through September 2001									
Alkalinity, Total	mg/l	107.78	99.00	23.90	95.00	170.00	9	1	10
BOD (5) Day	mg/l	-	-	-	0.00	-	0	10	10
Carbon, Organic, Dissolved	mg/l	4.07	3.90	0.32	3.80	4.70	11	0	11
Carbon, Organic, Total	mg/l	4.24	4.10	0.55	3.50	5.50	11	0	11
Chloride, Total	mg/l	13.05	13.00	2.76	7.50	16.00	11	0	11
Chlorophyll <i>a</i>	µg/l	6.11	1.60	13.13	1.00	40.30	10	0	10
Hardness, Total	mg/l	149.80	151.00	12.30	130.00	167.00	10	0	10
Nitrogen, Ammonia (as N)	mg/l	0.14	0.16	0.08	0.05	0.26	5	6	11
Nitrogen, Kjeldahl, Dissolved (as N)	mg/l	0.55	0.57	0.19	0.23	0.84	9	2	11
Nitrogen, Kjeldahl, Total (as N)	mg/l	0.55	0.50	0.23	0.23	0.89	10	1	11
Nitrogen, Nitrite (as N)	mg/l	0.03	0.03	0.01	0.02	0.04	2	4	6
Nitrogen, Nitrate (as N)	mg/l	0.71	0.76	0.44	0.06	1.20	6	0	6
Nitrogen, Nitrate-Nitrite (as N)	mg/l	0.76	0.65	0.52	0.07	1.84	10	1	11
Ortho-Phosphorus, Dissolved (as P)	mg/l	0.07	0.06	0.03	0.03	0.14	10	1	11
Phosphorus, Dissolved, Total (as P)	mg/l	0.07	0.06	0.04	0.03	0.16	11	0	11
Phosphorus, Total (as P)	mg/l	0.10	0.09	0.04	0.07	0.17	10	1	11
Solids Settleable	ml/l	-	-	-	0.00	-	0	10	10
Solids, Total Dissolved	mg/l	249.22	248.00	27.44	210.00	300.00	9	1	10
Solids, Total Suspended	ml/l	33.83	14.00	64.53	5.92	227.00	11	0	11
Solids, Volatile	mg/l	19.80	19.80	19.09	6.30	33.30	2	3	5
Solids, Volatile Suspended	mg/l	5.00	5.00	1.41	4.00	6.00	2	3	5
Sulfate	mg/l	42.60	45.10	8.42	29.70	49.70	5	0	5
Sulfate, Dissolved	mg/l	79.25	48.00	67.43	41.00	180.00	4	1	5
Turbidity	NTU	40.19	38.00	21.99	13.20	89.00	9	1	10

Table 3.2-4. Results of metals analysis (March 2001) at the Verdigris River (Lenapah), Big Creek (near Childers), and the Verdigris River (below the Oologah Lake Dam).

Constituent	Units	Verdigris River at Lenapah (March 12, 2001)	Big Creek Near Childers (March 12, 2001)	Verdigris River below Oologah Dam (March 13, 2001)
Aluminum, Dissolved	mg/l	6	0.37	0.49
Aluminum, Total	mg/l	36	1.5	0.96
Antimony, Dissolved	mg/l	<0.005	<0.005	<0.005
Antimony, Total	mg/l	<0.005	<0.005	<0.005
Arsenic, Dissolved	mg/l	<0.002	<0.002	<0.002
Arsenic, Total	mg/l	0.0037	<0.002	<0.002
Barium, Dissolved	mg/l	0.058	0.041	0.043
Barium, Total	mg/l	0.16	0.052	0.052
Beryllium, Dissolved	mg/l	0.002	0.003	0.008
Beryllium, Total	mg/l	<0.002	0.002	<0.002
Cadmium, Dissolved	mg/l	<0.003	<0.003	<0.003
Cadmium, Total	mg/l	0.003	<0.003	<0.003
Calcium, Dissolved	mg/l	29	49	36
Calcium, Total	mg/l	44	61	46
Chromium, Dissolved	mg/l	<0.025	<0.025	<0.025
Chromium, Total	mg/l	<0.025	<0.025	<0.025
Copper, Dissolved	mg/l	<0.02	<0.02	<0.02
Copper, Total	mg/l	<0.02	<0.02	<0.02
Iron, Dissolved	mg/l	2.7	0.25	0.33
Iron, Total	mg/l	52	1.3	0.74
Lead, Dissolved	mg/l	<0.002	<0.002	<0.002
Lead, Total	mg/l	<0.002	<0.002	<0.002
Magnesium, Dissolved	mg/l	4.8	3.5	7.2
Magnesium, Total	mg/l	8.5	4.5	9
Manganese, Dissolved	mg/l	0.02	<0.02	<0.02
Manganese, Total	mg/l	0.33	0.039	0.023
Mercury, Dissolved	mg/l	<0.0002	<0.0002	<0.0002
Mercury, Total	mg/l	<0.0002	<0.0002	<0.0002
Nickel, Dissolved	mg/l	<0.02	<0.02	<0.02
Nickel, Total	mg/l	<0.02	<0.02	<0.02
Potassium, Dissolved	mg/l	3	1.6	3.2
Potassium, Total	mg/l	4.5	2.1	3.3
Selenium, Dissolved	mg/l	<0.002	<0.002	<0.002
Selenium, Total	mg/l	<0.002	<0.002	<0.002
Silicon, Dissolved	mg/l	7	2.8	2.1
Silicon, Total	mg/l	17	3.5	2.3
Silver, Dissolved	mg/l	<0.003	<0.003	<0.003
Silver, Total	mg/l	<0.003	<0.003	<0.003
Sodium, Dissolved	mg/l	8.8	5.5	9.4
Sodium, Total	mg/l	16	9.6	16
Thallium, Dissolved	mg/l	<0.002	<0.002	<0.002
Thallium, Total	mg/l	<0.002	<0.002	<0.002
Zinc, Dissolved	mg/l	<0.02	<0.02	<0.02
Zinc, Total	mg/l	0.18	<0.02	<0.02

Table 3.2-5. Statistical summaries of continuously monitored data at the Verdigris River at Lenapah for April through September 2000, 2001, and April 2000 through September 2001.

	Conductivity μS/cm	DO mg/l	pH Units	Water Temp. °C	Turbidity NTU	Stage ft.	Discharge Cfs
April through September 2000							
Mean	376	7.49	*	24.82	96.13	5.71	1,857
Median	376	7.26	7.92	25.55	44.60	4.79	483
St. Dev.	97	1.58	0.27	4.56	148.84	3.99	4,268
Minimum	139	2.97	7.07	5.20	5.20	1.15	5
Maximum	604	13.37	8.76	34.05	1,140.90	29.36	32,993
N	4,194	4,205	4,190	4,214	4,006	4,295	4,298
April through September 2001							
Mean	379	7.48	*	24.81	119.65	5.51	1,510
Median	376	7.97	7.91	24.48	40.80	5.05	717
St. Dev.	101	2.25	0.79	4.69	166.17	2.56	2,457
Minimum	78	0.17	5.35	10.55	0.30	0.00	33
Maximum	795	13.24	8.83	34.65	1,211.50	35.00	44,287
N	4,294	4,218	4,294	4,304	4,294	4,311	4,304
April 2000 through September 2001							
Mean	386	7.94	*	19.03	85.45	5.68	1,842
Median	386	7.90	7.93	21.67	38.60	4.55	431
St. Dev.	104	2.70	0.55	9.80	141.01	3.52	3,623
Minimum	78	0.17	5.35	0.03	0.30	0.00	5
Maximum	795	14.61	9.22	34.65	1,211.50	35.00	44,287
N	12,669	11,631	12,709	12,722	12,526	12,890	12,885

Table 3.2-6. Statistical summaries of continuously monitored data at Big Creek near Childers for April through September 2000, April through July 2001, and April 2000 through July 2001.

	Conductivity μS/cm	DO mg/l	pH Units	Water Temp. °C	Turbidity NTU	Stage ft.	Discharge Cfs
April through September 2000							
Mean	324	6.35	*	24.53	46.00	9.28	162
Median	335	7.10	7.88	25.04	13.15	9.08	7
St. Dev.	84	3.02	0.24	4.83	168.82	1.37	1,128
Minimum	63	0.02	7.21	11.88	0.10	8.20	0
Maximum	454	14.58	9.07	34.13	5,453.00	23.59	16,951
N	3,593	3,513	3,583	3,594	3,412	4,042	3,080
April through July 2001							
Mean	355	7.83	*	24.10	46.95	9.23	81
Median	339	7.87	7.91	23.73	18.10	9.16	19
St. Dev.	79	1.74	0.22	4.72	120.22	0.47	255
Minimum	64	0.17	7.26	9.00	0.10	7.15	0
Maximum	652	12.53	8.45	35.92	1,162.90	13.23	2,885
N	2,777	2,546	2,786	2,781	2,640	2,789	2,789
April 2000 through July 2001							
Mean	347	8.33	*	18.01	46.33	9.27	139
Median	342	8.14	7.91	20.08	15.00	9.14	16
St. Dev.	113	3.57	0.22	9.66	149.47	1.02	721
Minimum	50	0.02	7.21	0.07	0.10	4.79	0
Maximum	685	14.58	9.07	35.92	5,453.00	23.59	16,951
N	10,272	10,074	10,243	10,416	9,882	10,931	9,985

Table 3.2-7. Statistical summaries of continuously monitored data at the Verdigris River below the Oologah Lake Dam for April through September 2000, 2001, and April 2000 through September 2001.

	Conductivity μS/cm	DO mg/l	pH Units	Water Temp. °C	Turbidity NTU	Flow in cfs	Flow out cfs	Elev. ft.	Storage ac-ft
April through September 2000									
Mean	324	7.34	*	24.12	58.80	2,706	2,785	639.59	606,480
Median	310	7.38	7.72	25.24	38.50	100	10	639.61	603,888
St. Dev.	51	1.72	0.30	3.53	59.36	6,976	5,390	2.46	83,949
Minimum	251	3.62	7.33	14.82	4.50	0	0	636.42	505,514
Maximum	485	14.30	8.85	31.41	1,131.10	75,240	24,570	647.28	886,690
N	3,507	3,690	3,689	3,690	3,683	4,355	4,368	4,358	4,357
April through September 2001									
Mean	352	7.26	*	22.20	47.50	12,914	1,209	638.22	559,180
Median	334	7.65	7.79	24.32	44.30	244	224	638.15	556,967
St. Dev.	52	1.98	0.25	4.92	27.29	179,945	2,255	0.40	12,496
Minimum	297	1.02	7.31	9.35	12.00	0	0	637.00	522,014
Maximum	525	14.51	8.42	80.06	140.50	4,019,582	10,677	639.45	598,637
N	4,172	4,210	4,189	4,201	4,189	4,342	4,352	4,168	4,168
April 2000 through September 2001									
Mean	403	8.32	*	17.97	63.00	6,068	2,089	638.80	580,688
Median	335	7.96	7.92	20.81	36.10	180	0	638.13	556,333
St. Dev.	189	2.77	0.39	8.54	108.73	104,185	4,247	2.29	77,771
Minimum	241	1.02	7.31	1.32	4.50	0	0	635.91	491,136
Maximum	1,290	14.62	9.04	80.06	1,131.10	4,019,582	24,570	647.28	886,690
N	11,897	11,432	12,099	12,112	10,815	13,011	13,044	12,796	12,795

Table 3.2-8. Regression equations for estimates of alkalinity, hardness, total dissolved solids, total suspended solids, chloride, sulfate, total organic carbon, total nitrogen, total Kjeldahl nitrogen, total phosphorus, dissolved phosphorus, and dissolved ortho-phosphorus at the Verdigris River (Lenapah) and Big Creek (near Childers). Sampling and continuous data from April – September 2000 and 2001.

Constituent	Equation	MSE	R ²
Verdigris River at Lenapah, OK			
Alkalinity (<i>Alk</i>)	$\log_{10}Alk = 0.668*\log_{10}SC + 0.0533*pH + 0.00939*TEMP - 0.262$	0.0024	0.911
Hardness (<i>HARD</i>)	$\log_{10}HARD = 0.675*\log_{10}SC + 0.16*\log_{10}DO + 0.665*\log_{10}TEMP - 0.606$	0.0012	0.953
Solids, Total Dissolved (<i>TDS</i>)	$TDS = 242*\log_{10}SC - 70.2*\log_{10}DO - 38.8*pH - 23.6$	310	0.860
Solids, Total Suspended (<i>TSS</i>)	$TSS = 0.691*SC + 1.23*TURB - 268$	17,200	0.831
Chloride (<i>Cl</i>)	$\log_{10}Cl = 0.957*\log_{10}SC - 0.0892*\log_{10}FLOW - 0.929$	0.014	0.814
Sulfate, Dissolved (<i>SO₄</i>)	$SO_4 = 286*\log_{10}SC - 9.74*DO + 94.1*\log_{10}TURB - 806$	534	0.727
Carbon, Total Organic (<i>TOC</i>)	$TOC = -7.38 \log_{10}DO - 18.6*\log_{10}TEMP + 36.8$	0.745	0.579
Nitrogen, Total, Calculated (<i>TN</i>)	$TN = 2.73*\log_{10}SC + 0.310*pH + 2.72*\log_{10}TURB - 12.9$	0.312	0.844
Nitrogen, Total Kjeldahl (<i>TKN</i>)	$TKN = 1.90*\log_{10}SC + 0.351*pH + 2.35*\log_{10}TURB - 10.8$	0.273	0.840
Phosphorus, Total (<i>TP</i>)	$\log_{10}TP = -0.0376*DO + 0.125*\log_{10}FLOW + 0.527*\log_{10}TURB - 1.89$	0.039	0.856
Phosphorus, Dissolved (<i>DP</i>)	$DP = -0.0739*\log_{10}SC + 0.0307*\log_{10}TURB + 0.192$	0.0004	0.738
Phosphorus, Ortho, Dissolved (<i>DOP</i>)	$DOP = -0.00501*DO - 0.0304*pH + 0.0276*\log_{10}TURB + 0.275$	0.0005	0.626
Big Creek Near Childers, OK			
Alkalinity (<i>Alk</i>)	$\log_{10}Alk = 0.691*pH - 0.488*\log_{10}STAGE - 2.84$	0.0106	0.833
Hardness (<i>HARD</i>)	$HARD = 0.287*SC - 25.2*\log_{10}TURB + 102$	376	0.906
Solids, Total Dissolved (<i>TDS</i>)	$\log_{10}TDS = 0.000263*SC - 0.276*pH - 0.0292*STAGE + 4.69$	0.0019	0.889
Solids, Total Suspended (<i>TSS</i>)	$TSS = 111*\log_{10}SC + 1.27*TURB - 285$	10,900	0.760
Chloride (<i>Cl</i>)	$Cl = 0.0234*SC + 0.390*STAGE - 5.49$	2.76	0.665
Sulfate, Dissolved (<i>SO₄</i>)	$SO_4 = 0.0260*SC - 33.0*\log_{10}DO - 77.0*\log_{10}TEMP + 139$	151	0.267
Carbon, Total Organic (<i>TOC</i>)	$\log_{10}TOC = -0.000449*SC + 0.178*\log_{10}TURB + 0.520$	0.0083	0.858
Nitrogen, Total, Calculated (<i>TN</i>)	$TN = -0.58*\log_{10}SC - 0.79*pH + 0.169*\log_{10}TURB + 8.17$	0.265	0.496
Nitrogen, Total Kjeldahl (<i>TKN</i>)	$\log_{10}TKN = 1.07*pH + 0.680*\log_{10}TURB - 9.64$	0.0987	0.713
Phosphorus, Total (<i>TP</i>)	$TP = -0.113*pH + 0.000905*TURB + 0.919$	0.0023	0.974
Phosphorus, Dissolved (<i>DP</i>)	$DP = -0.0403*\log_{10}SC + 0.0366*\log_{10}TURB + 0.00129*STAGE + 0.0612$	0.000095	0.958
Phosphorus, Ortho, Dissolved (<i>DOP</i>)	$DOP = -0.0438*\log_{10}SC - 0.05*pH + 0.000028*TURB + 0.517$	0.000016	0.982

MSE = mean square error, R = coefficient of determination, SC = specific conductance (µS/cm), DO = dissolved oxygen (mg/l), pH = pH, TURB = turbidity (NTU), TEMP = water temperature (°C), FLOW = discharge (cfs), STAGE = stream stage height (ft.). Units are mg/l for all chemical constituents.

Table 3.2-9. Median relative percentage differences between measured and estimated constituent concentrations at the Verdigris River (Lenapah) and Big Creek (near Childers).

Constituent	Verdigris River at Lenapah, OK	Big Creek near Childers, OK
Alkalinity	6.08	15.48
Hardness	3.37	7.27
Solids, Total Dissolved	5.05	7.06
Solids, Total Suspended	48.09	49.83
Chloride	12.74	21.63
Sulfate, Dissolved	72.19	47.78
Carbon, Total Organic	8.71	11.02
Nitrogen, Total, Calculated	12.82	176.87
Nitrogen, Total Kjeldahl	15.40	28.52
Phosphorus, Total	19.54	17.18
Phosphorus, Dissolved	20.30	14.18
Phosphorus, Ortho, Dissolved	17.96	9.98

Table 3.2-10. Comparisons of daily loads calculated from regression equations (estimated) and field samples (measured) at the Verdigris River (Lenapah) and Big Creek (near Childers) for total suspended solids, total nitrogen, and total phosphorus (April 2000 through September 2001).

	Estimated Total Suspended Solids Load (kg/d)	Measured Total Suspended Solids Load (kg/d)	Estimated Total Nitrogen Load (kg/d)	Measured Total Nitrogen Load (kg/d)	Estimated Total Phosphorus Load (kg/d)	Measured Total Phosphorus Load (kg/d)
Verdigris River at Lenapah, OK						
Mean	1,188,550	6,853,800	10,850	58,670	1,550	13,340
Median	41,230	292,640	2,010	7,430	100	310
St. Dev.	5,137,967	16,314,477	26,256	87,918	5,443	29,559
Min.	20	1,290	<10	50	<10	<10
Max.	99,134,950	70,292,440	296,460	288,580	81,460	134,750
N	11,382	21	9,721	21	11,317	23
Big Creek near Childers, OK						
Mean	152,070	128,410	500	330	140	220
Median	1,070	460	30	20	<10	<10
St. Dev.	1,110,213	319,026	29,711	7,517	995	559
Min.	<10	70	<10	10	<10	<10
Max.	23,540,130	962,610	68,050	1,860	21,440	1,770
N	7,069	9	7,711	6	7,453	10

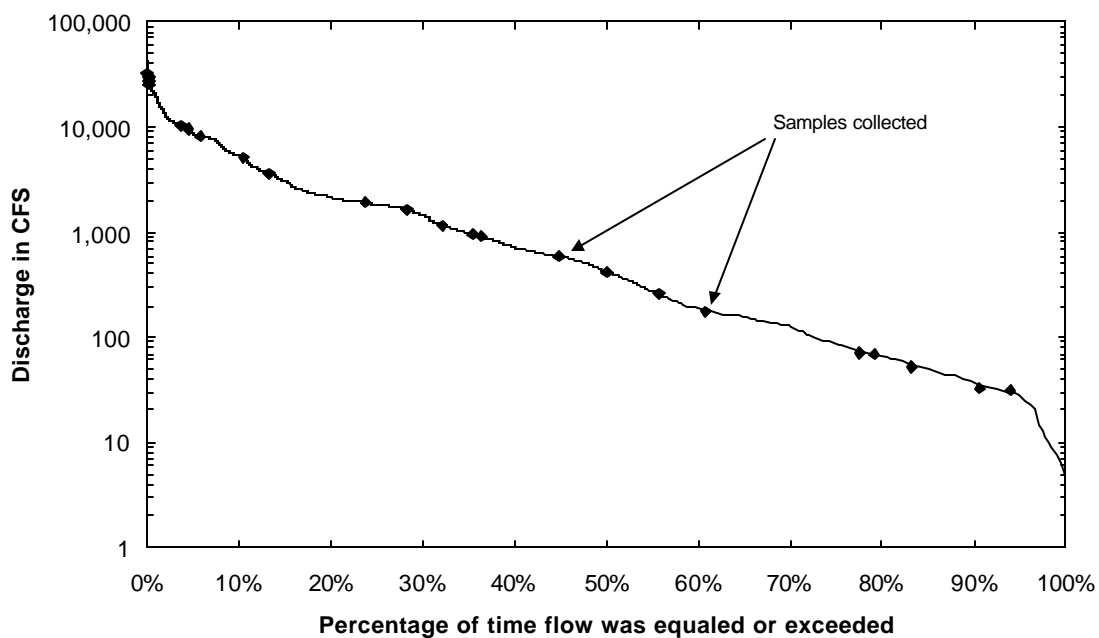


Figure 3.2-2
Flow-duration curve for the Verdigris River at Lenapah (April 2000 through September 2001)
with indications of stream discharge at which samples were collected.

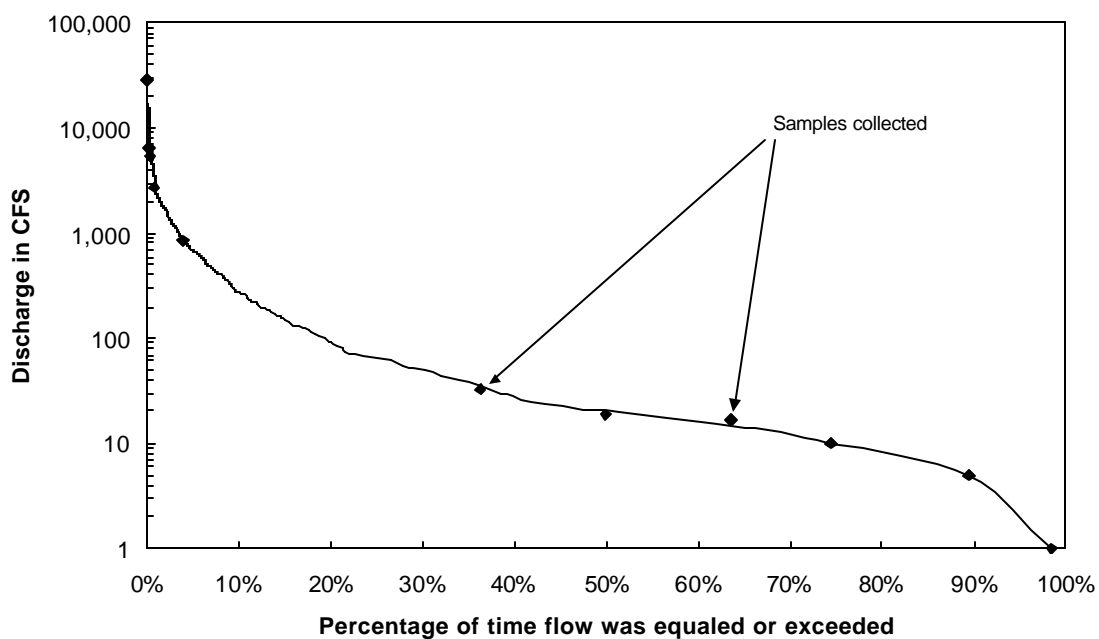


Figure 3.2-3
Flow-duration curve for Big Creek near Childers (April 2000 through September 2001)
with indications of stream discharge at which samples were collected.

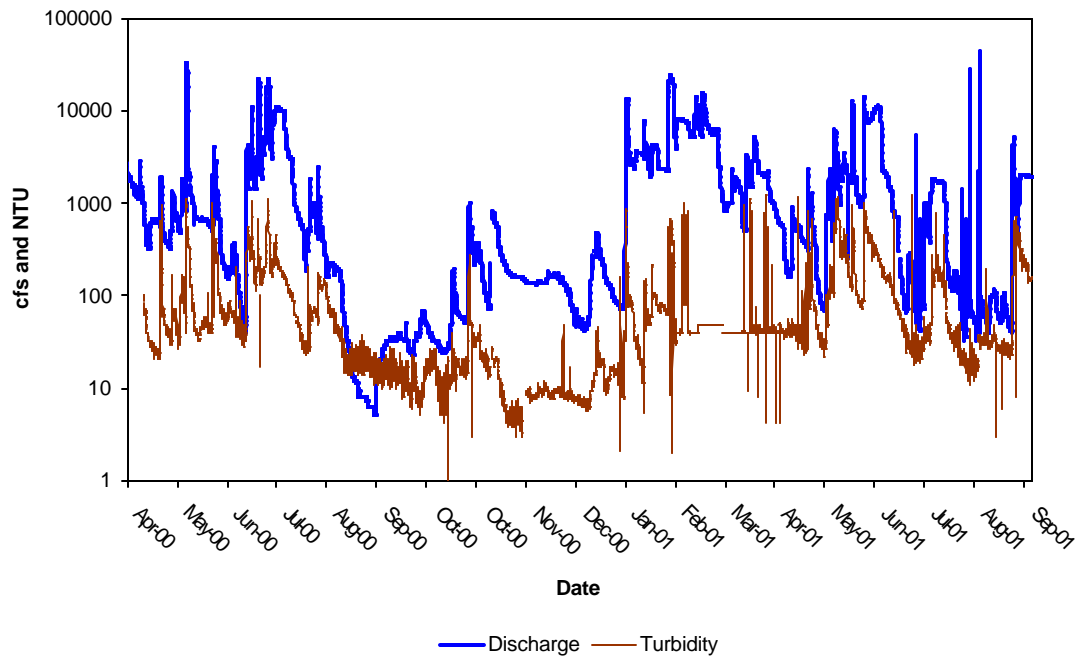


Figure 3.2-4
Comparison of hourly observations of discharge and turbidity at the Verdigris River at Lenapah, OK, from April 2000 through September 2001.

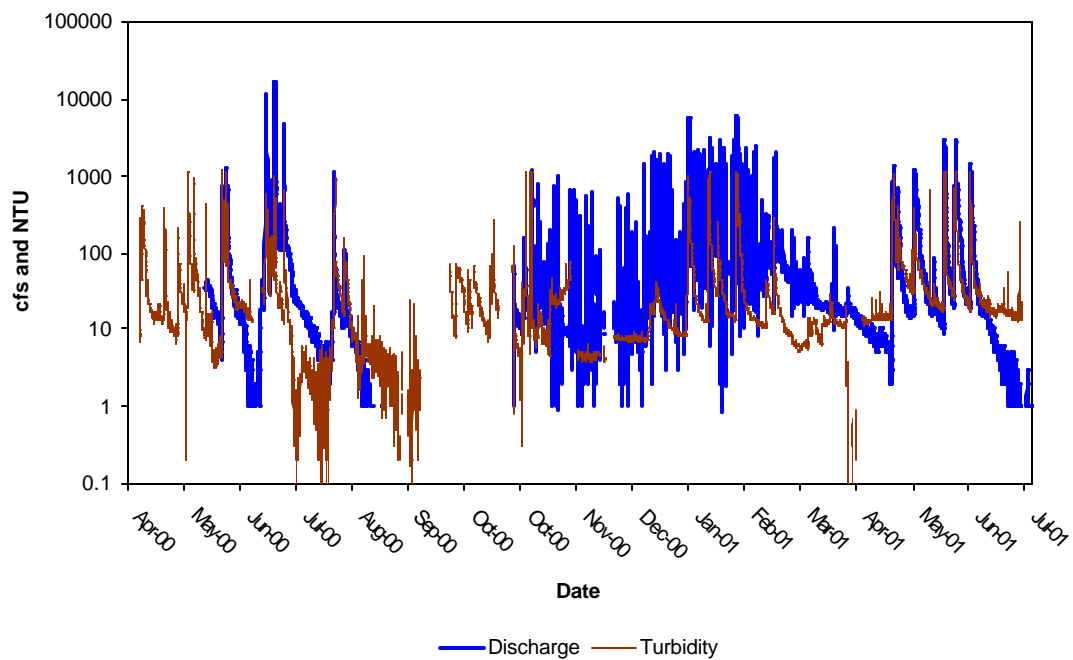


Figure 3.2-5
Comparison of hourly observations of discharge and turbidity at Big Creek near Childers, OK, April 2000 through July 2001.

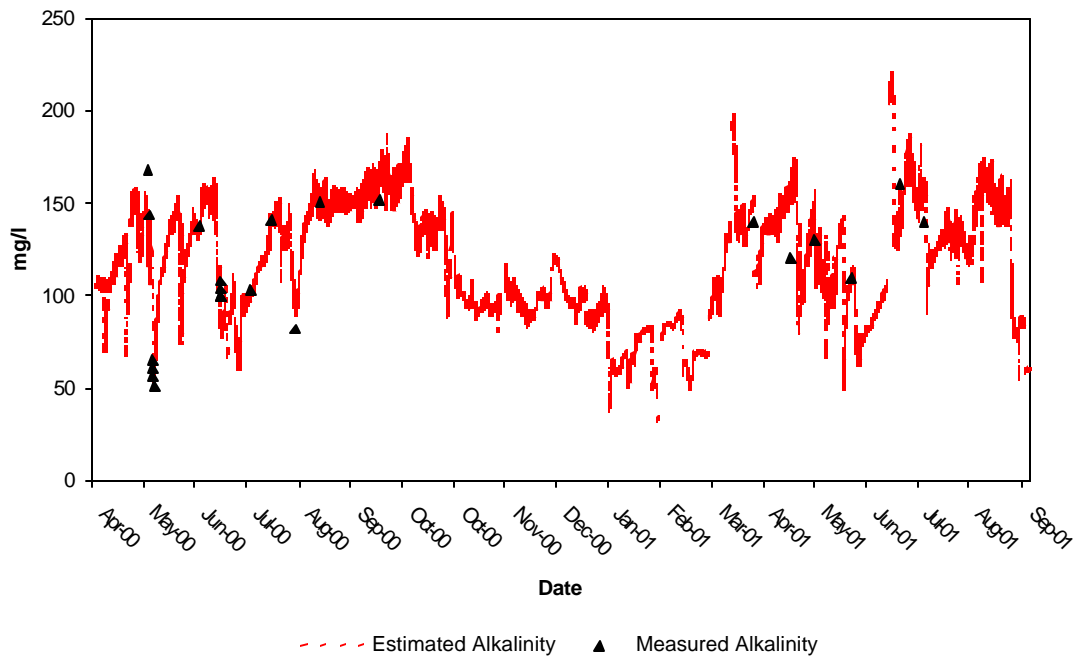


Figure 3.2-6
Comparison of measured and estimated total alkalinity concentration
at the Verdigris River (Lenapah), April 2000 through September 2001.

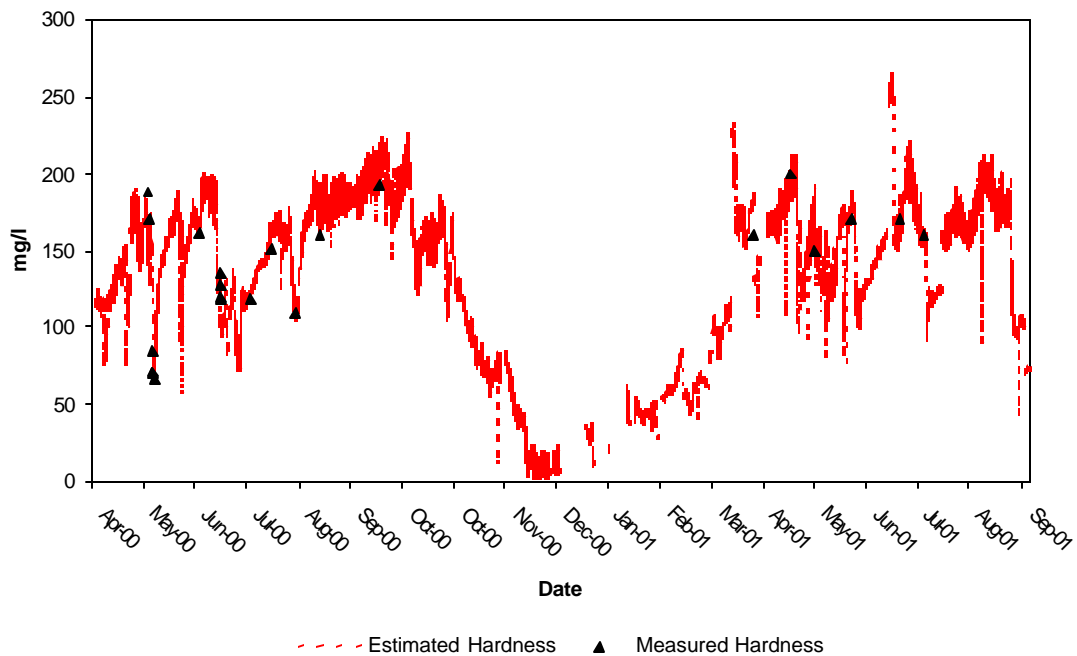


Figure 3.2-7
Comparison of measured and estimated total hardness concentration
at the Verdigris River (Lenapah), April 2000 through September 2001.

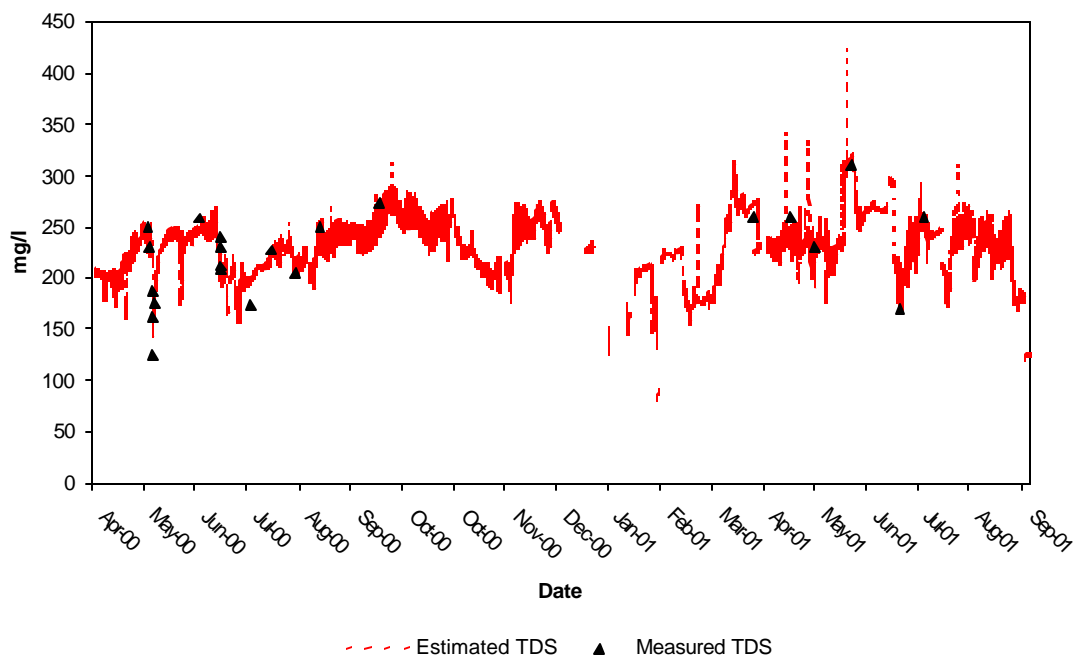


Figure 3.2-8
Comparison of measured and estimated total dissolved solids concentration
at the Verdigris River (Lenapah), April 2000 through September 2001.

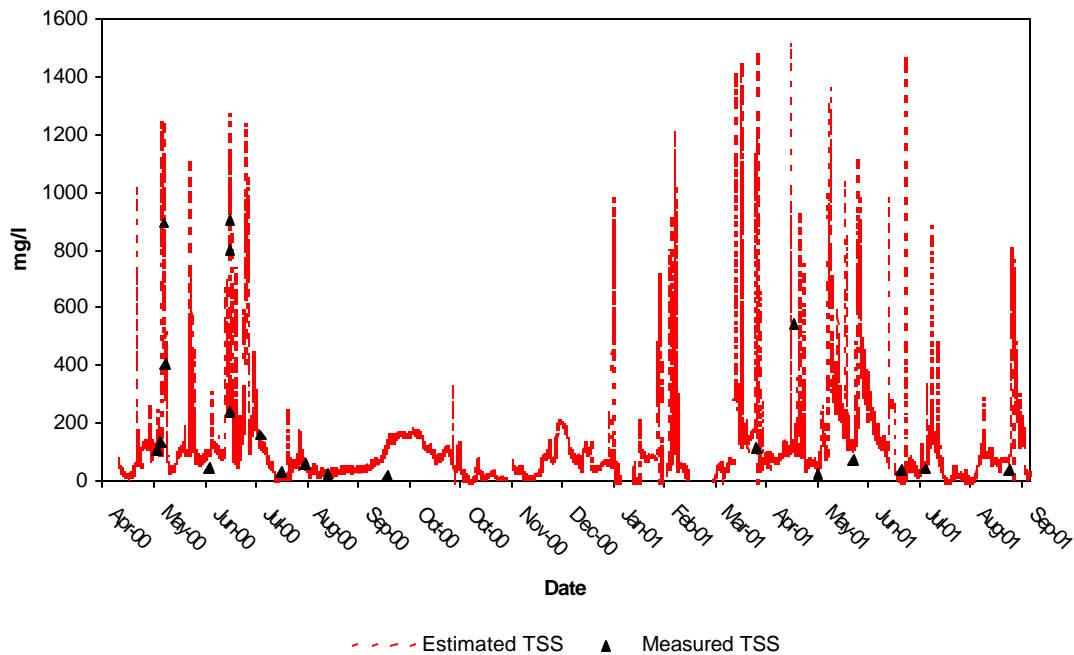


Figure 3.2-9
Comparison of measured and estimated total suspended solids concentration
at the Verdigris River (Lenapah), April 2000 through September 2001.

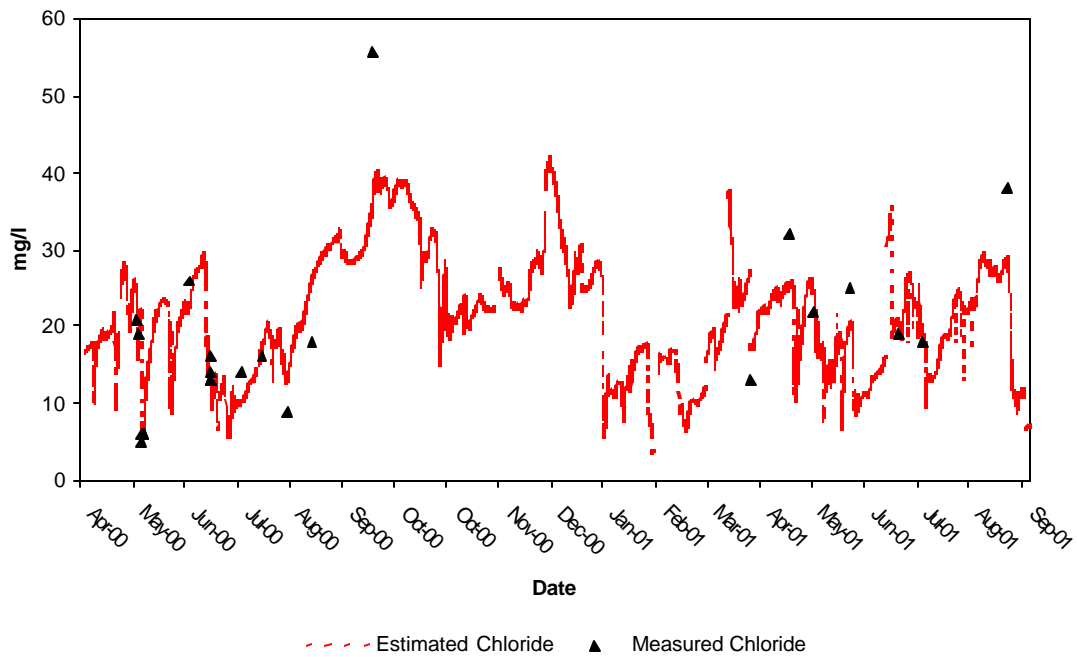


Figure 3.2-10
Comparison of measured and estimated chloride concentration
at the Verdigris River (Lenapah), April 2000 through September 2001.

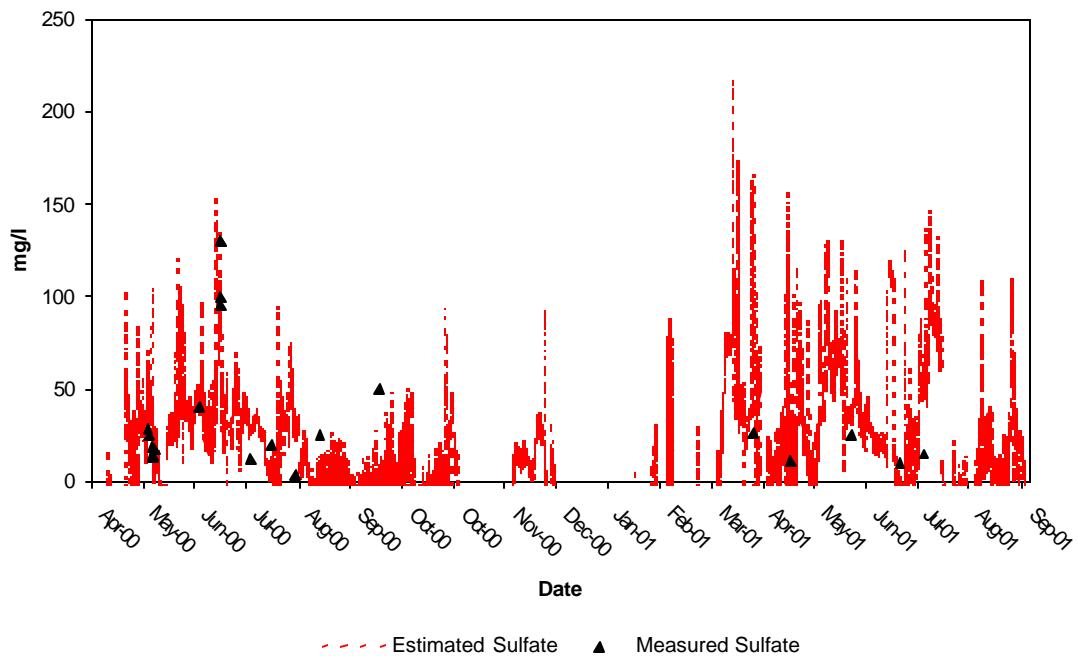


Figure 3.2-11
Comparison of measured and estimated sulfate concentration
at the Verdigris River (Lenapah), April 2000 through September 2001.

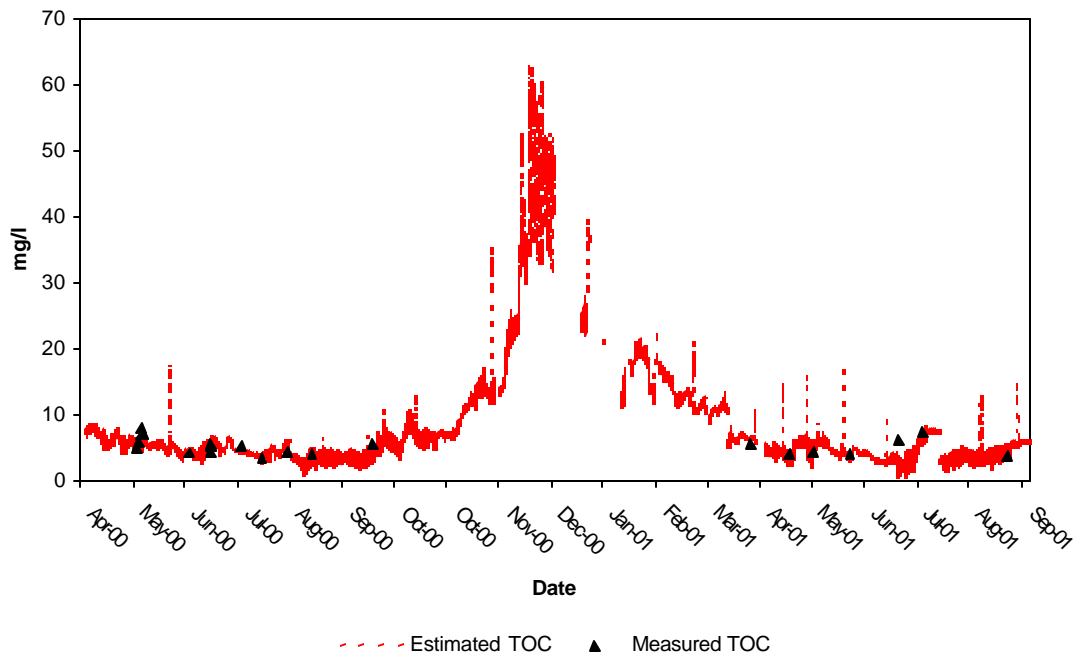


Figure 3.2-12
Comparison of measured and estimated total organic carbon concentration
at the Verdigris River (Lenapah), April 2000 through September 2001.

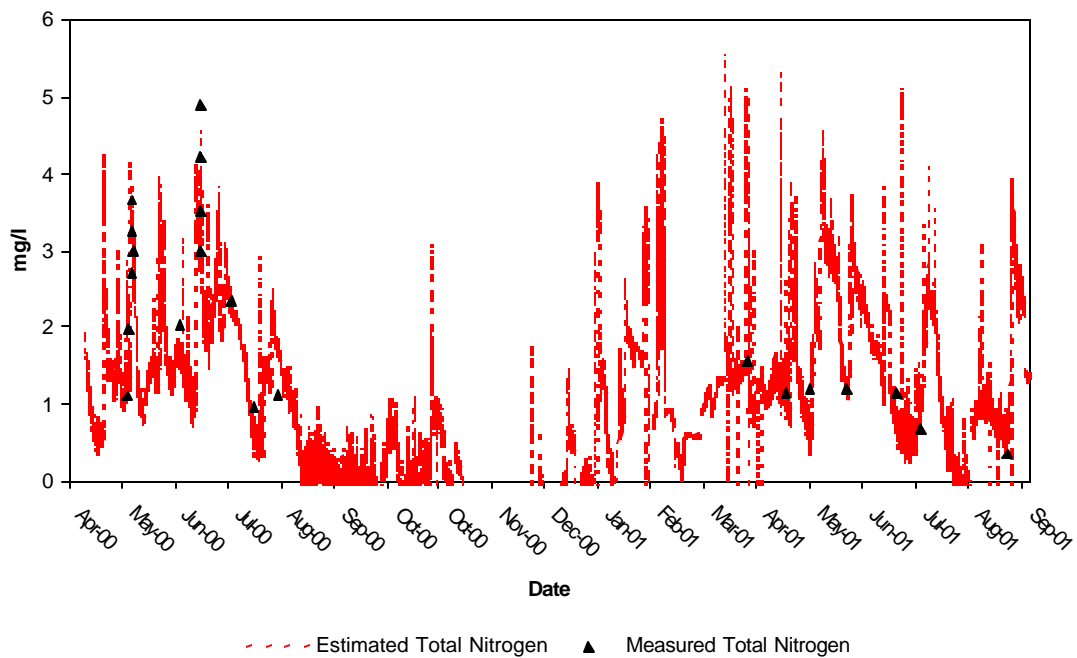


Figure 3.2-13
Comparison of measured and estimated total nitrogen concentration
at the Verdigris River (Lenapah), April 2000 through September 2001.

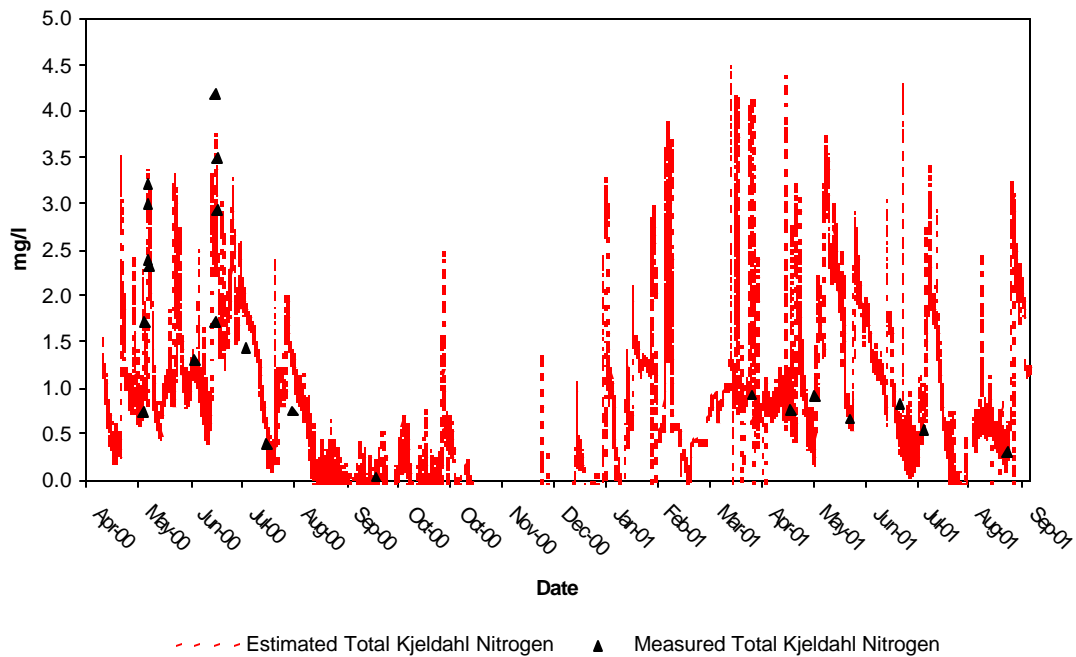


Figure 3.2-14
Comparison of measured and estimated total Kjeldahl nitrogen concentration
at the Verdigris River (Lenapah), April 2000 through September 2001.

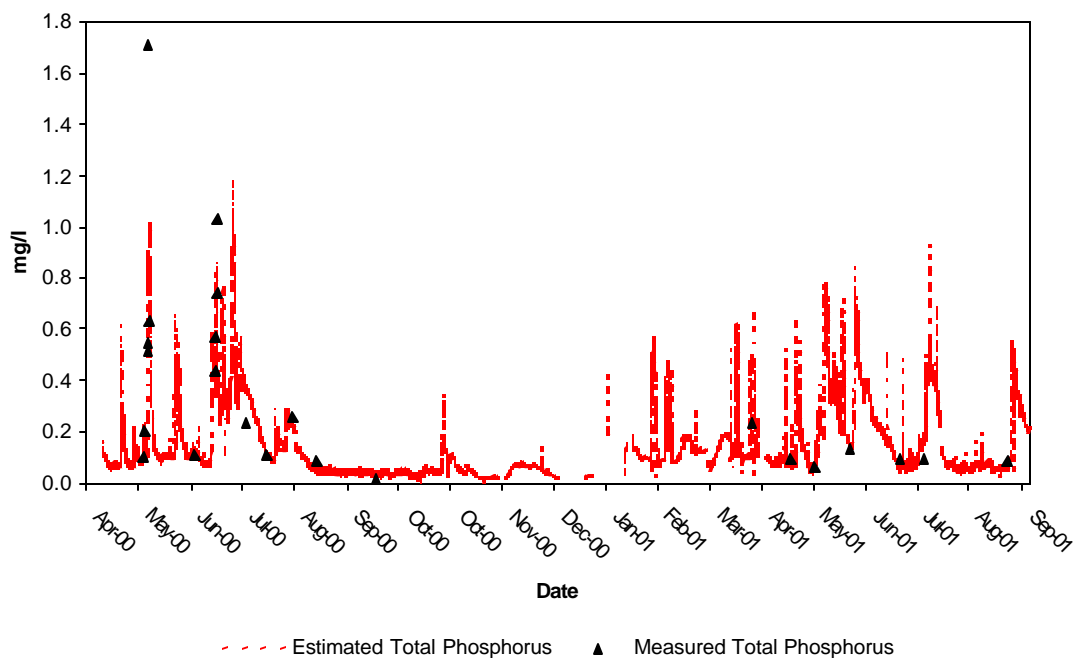


Figure 3.2-15
Comparison of measured and estimated total phosphorus concentration
at the Verdigris River (Lenapah), April 2000 through September 2001.

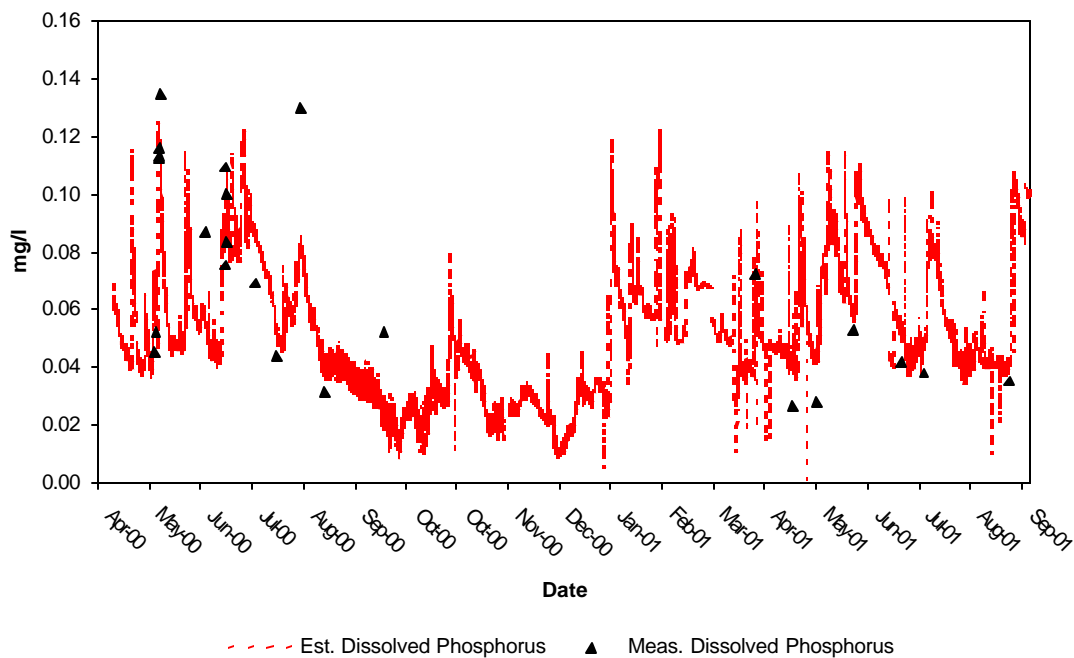


Figure 3.2-16
Comparison of measured and estimated dissolved phosphorus concentration
at the Verdigris River (Lenapah), April 2000 through September 2001.

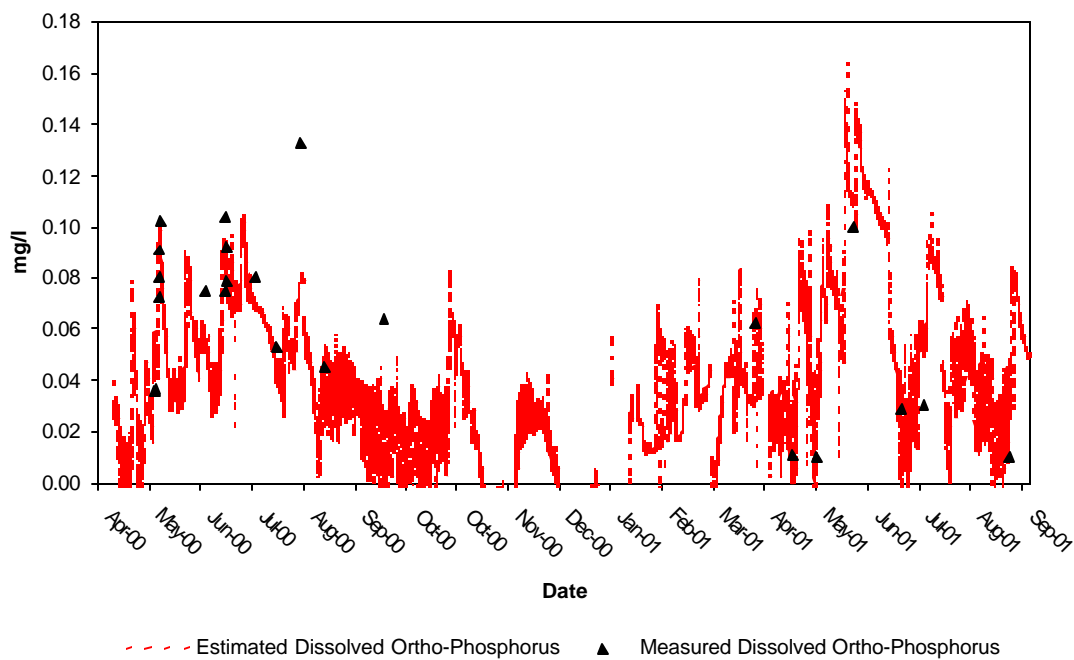


Figure 3.2-17
Comparison of measured and estimated dissolved ortho-phosphorus concentration
at the Verdigris River (Lenapah), April 2000 through September 2001.

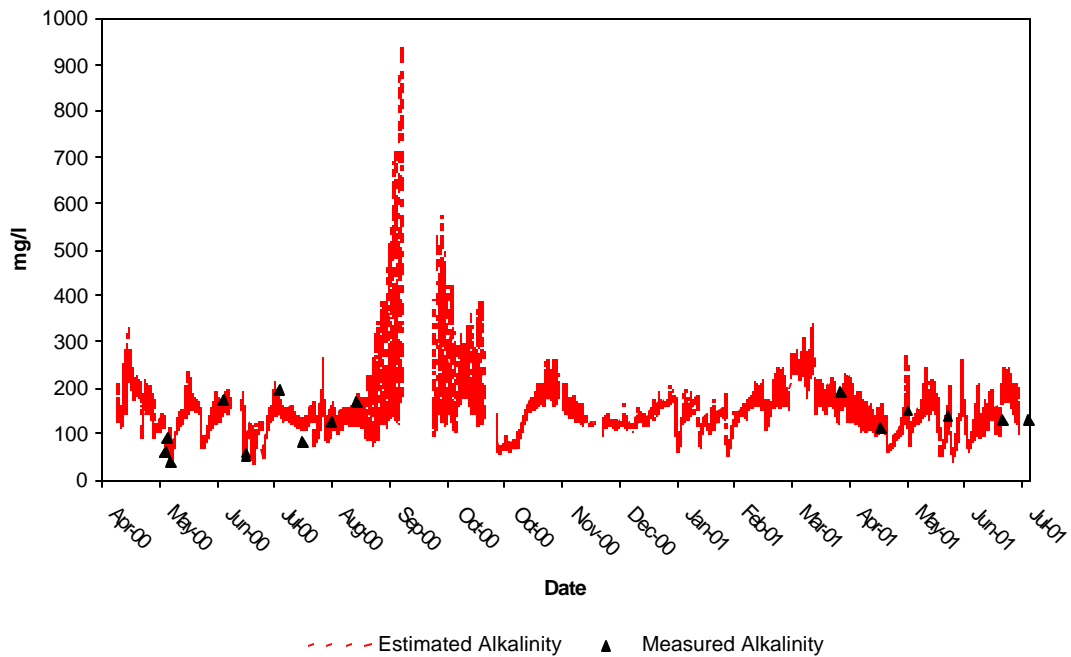


Figure 3.2-18
Comparison of measured and estimated total alkalinity concentration
at Big Creek (near Childers), April 2000 through July 2001.

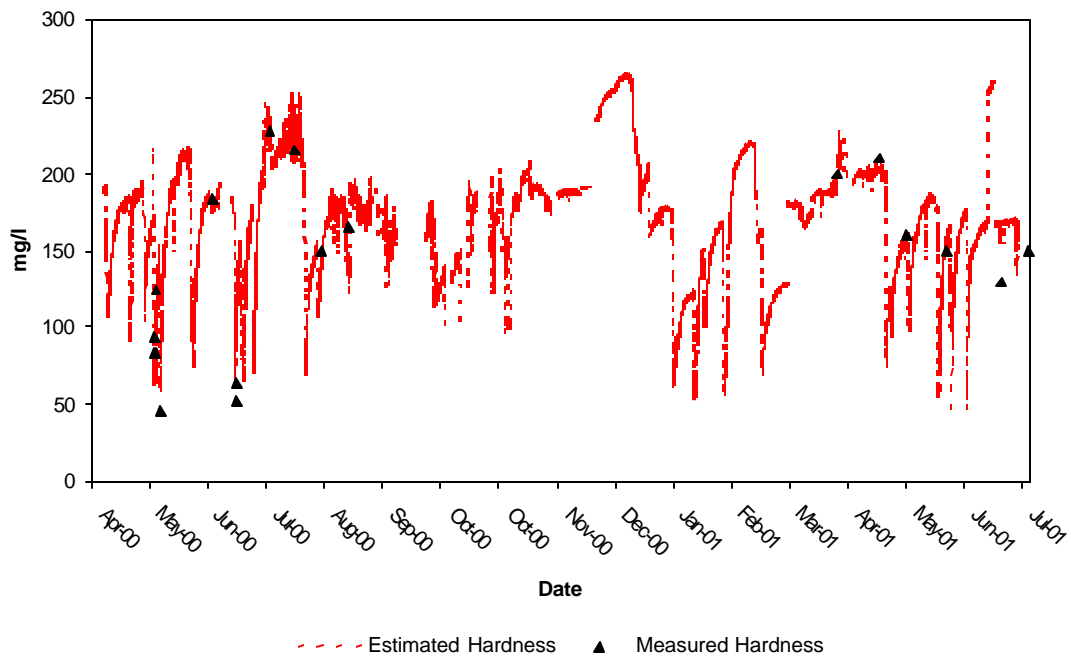


Figure 3.2-19
Comparison of measured and estimated total hardness concentration
at Big Creek (near Childers), April 2000 through July 2001.

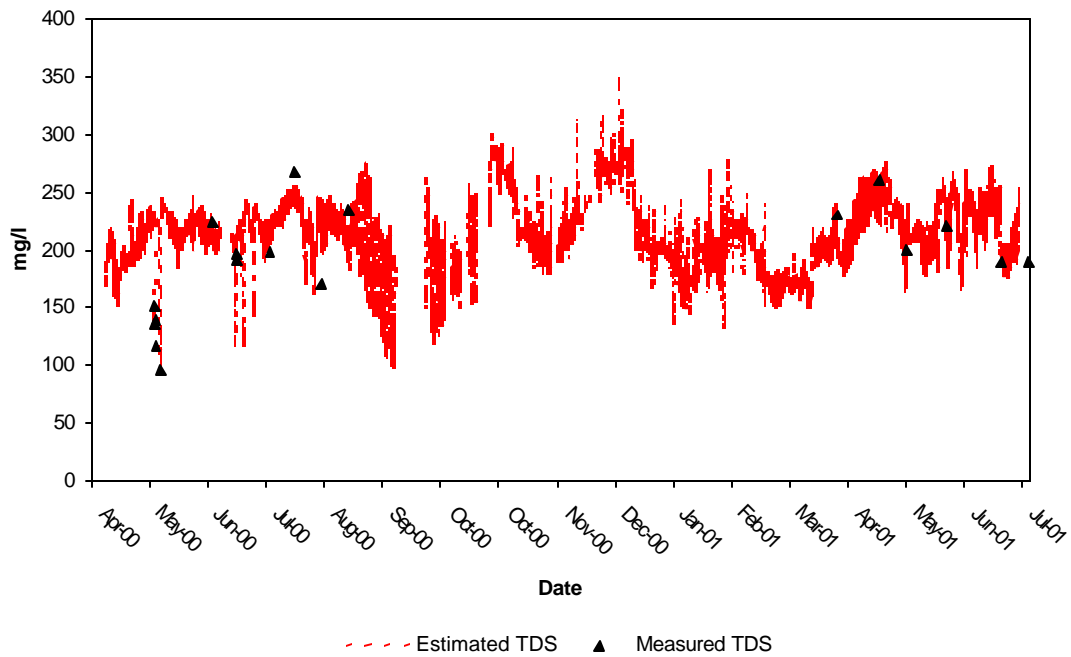


Figure 3.2-20
Comparison of measured and estimated total dissolved solids concentration
at Big Creek (near Childers), April 2000 through July 2001.

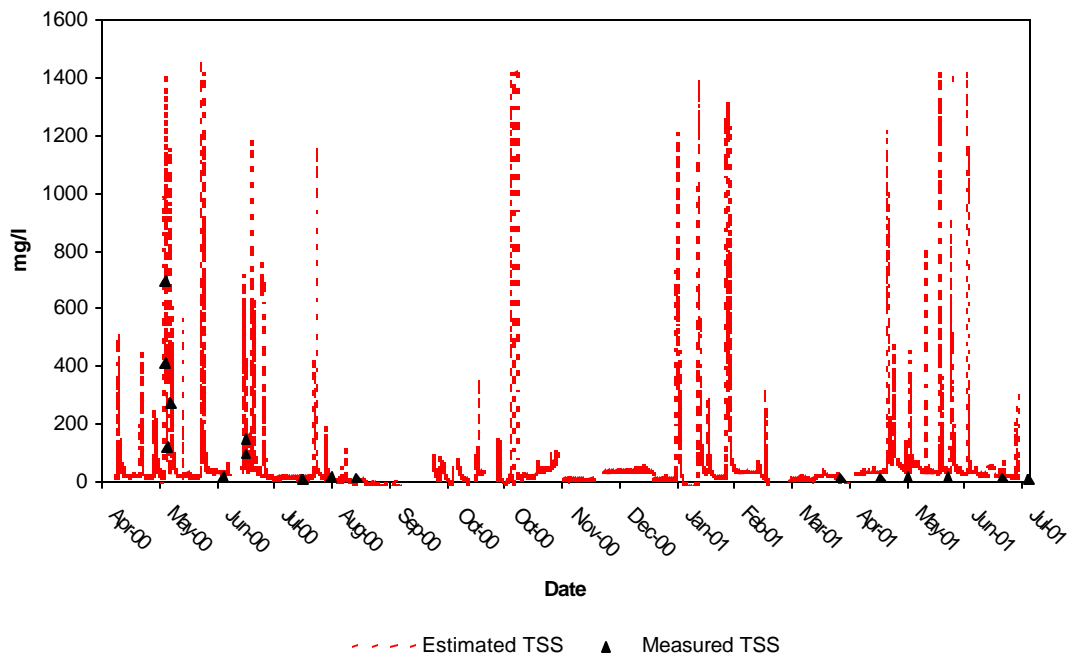


Figure 3.2-21
Comparison of measured and estimated total suspended solids concentration
at Big Creek (near Childers), April 2000 through July 2001.

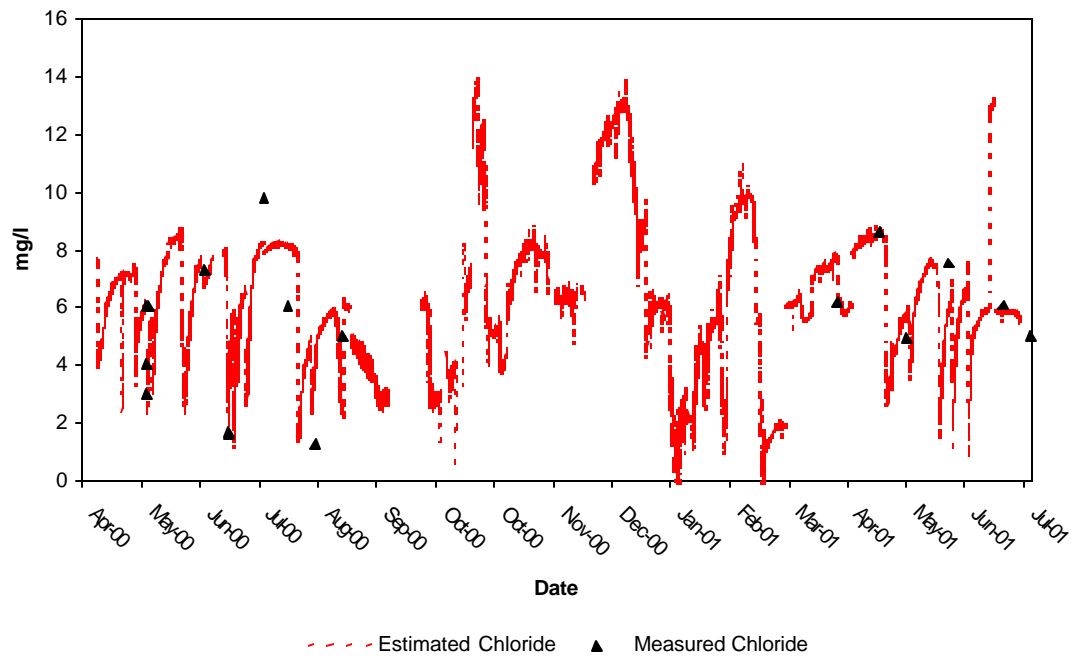


Figure 3.2-22
Comparison of measured and estimated chloride concentration
at Big Creek (near Childers), April 2000 through July 2001.

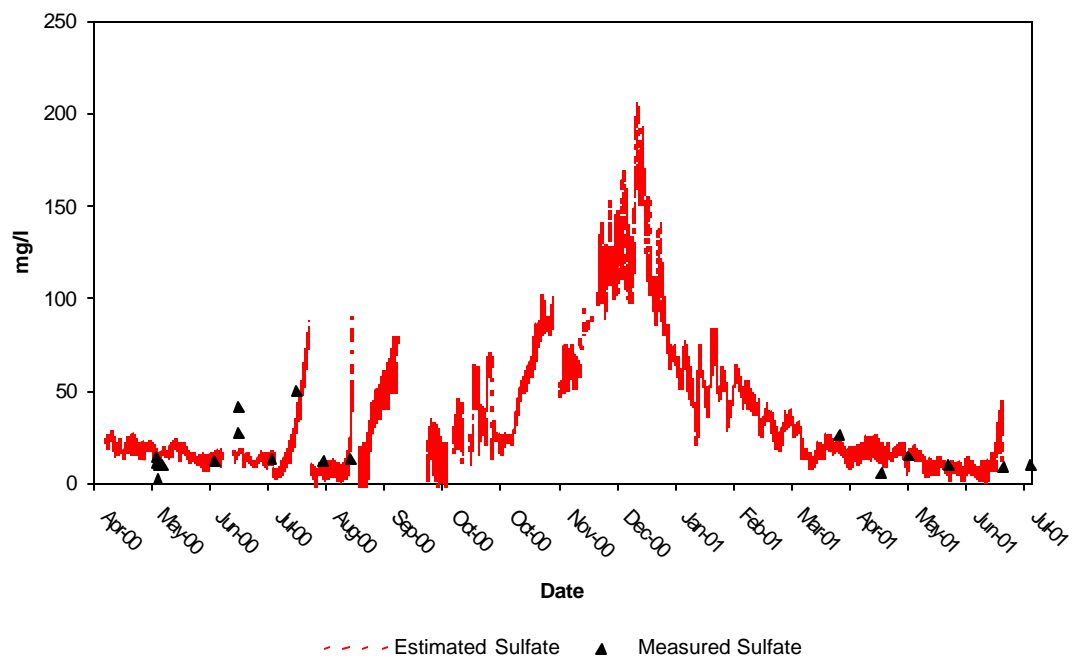


Figure 3.2-23
Comparison of measured and estimated sulfate concentration
at Big Creek (near Childers), April 2000 through July 2001.

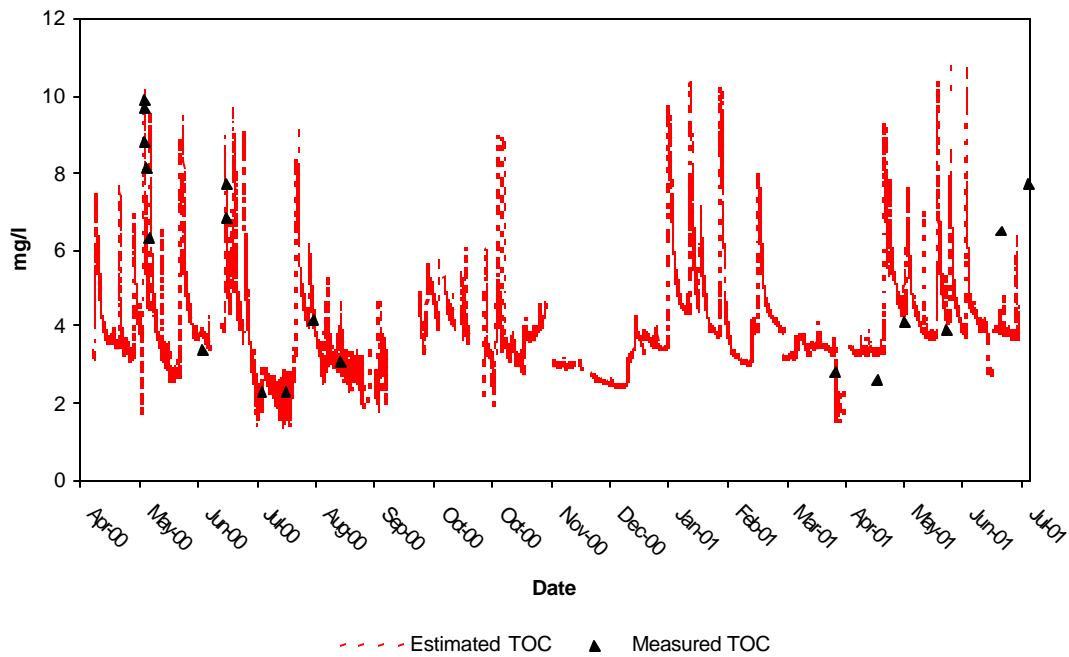


Figure 3.2-24
Comparison of measured and estimated total organic carbon concentration
at Big Creek (near Childers), April 2000 through July 2001.

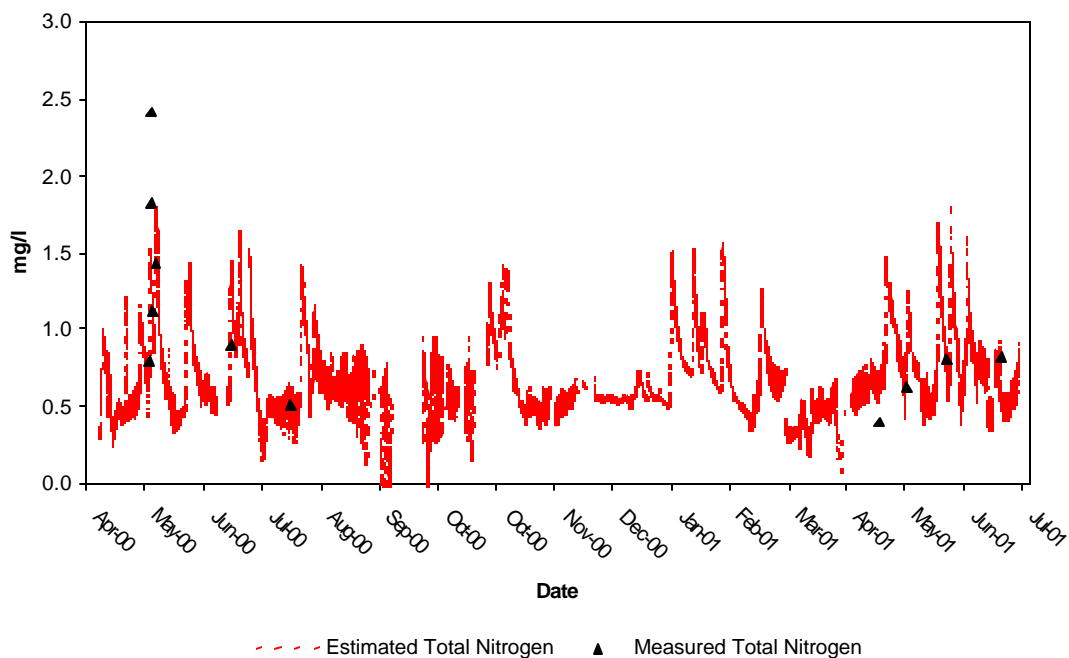


Figure 3.2-25
Comparison of measured and estimated total nitrogen concentration
at Big Creek (near Childers) April 2000 through July 2001.

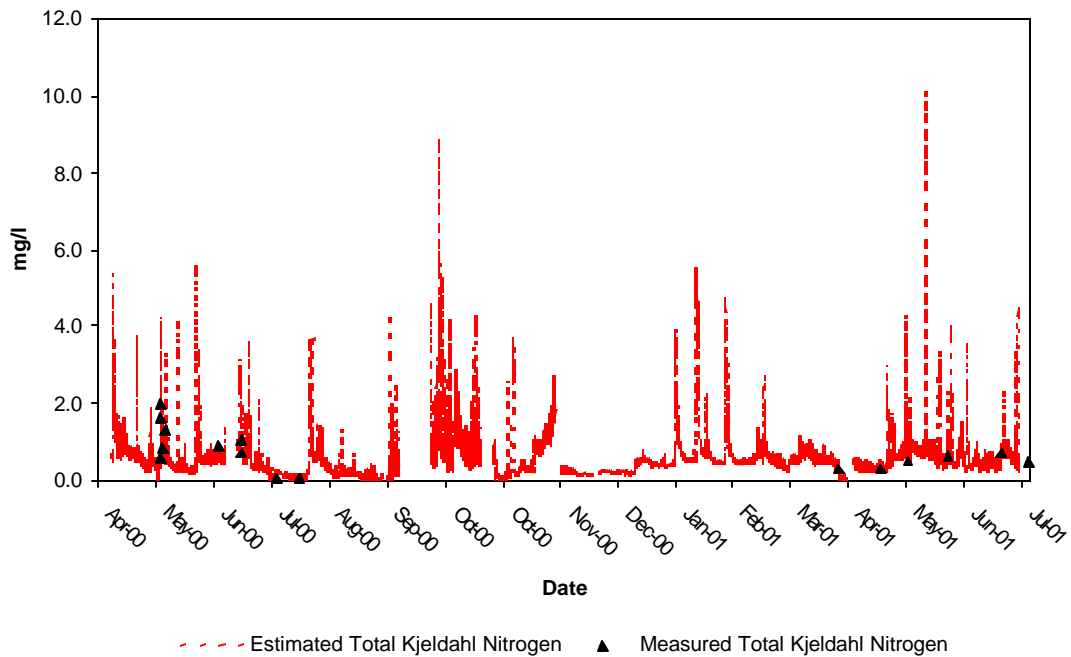


Figure 3.2-26
Comparison of measured and estimated total Kjeldahl nitrogen concentration
at Big Creek (near Childers), April 2000 through July 2001.

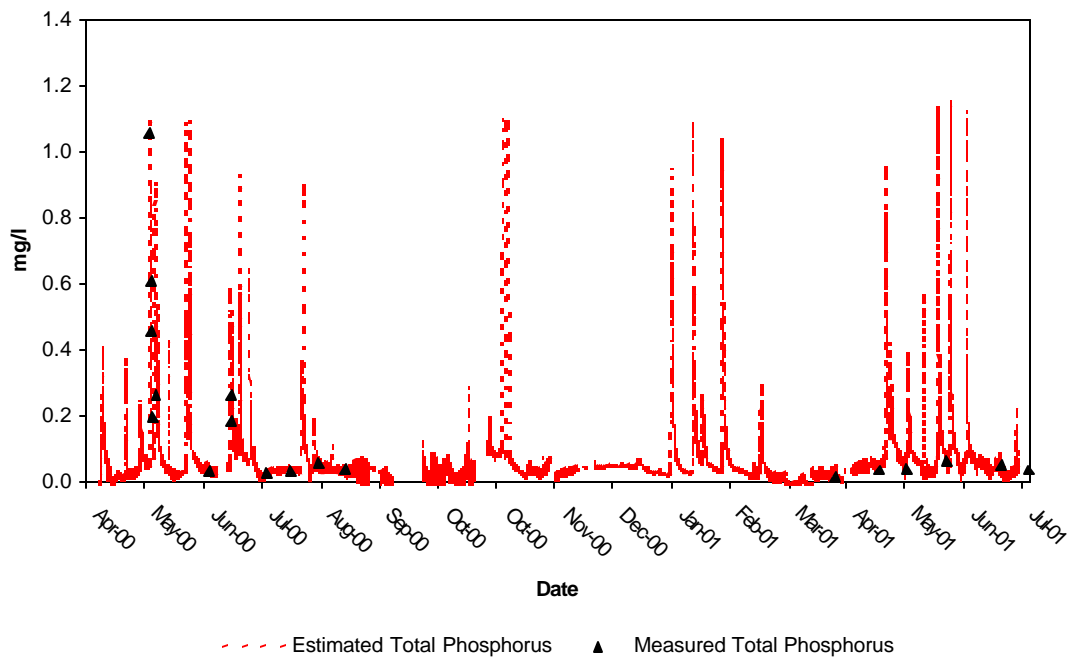


Figure 3.2-27
Comparison of measured and estimated total phosphorus concentration
at Big Creek (near Childers), April 2000 through July 2001.

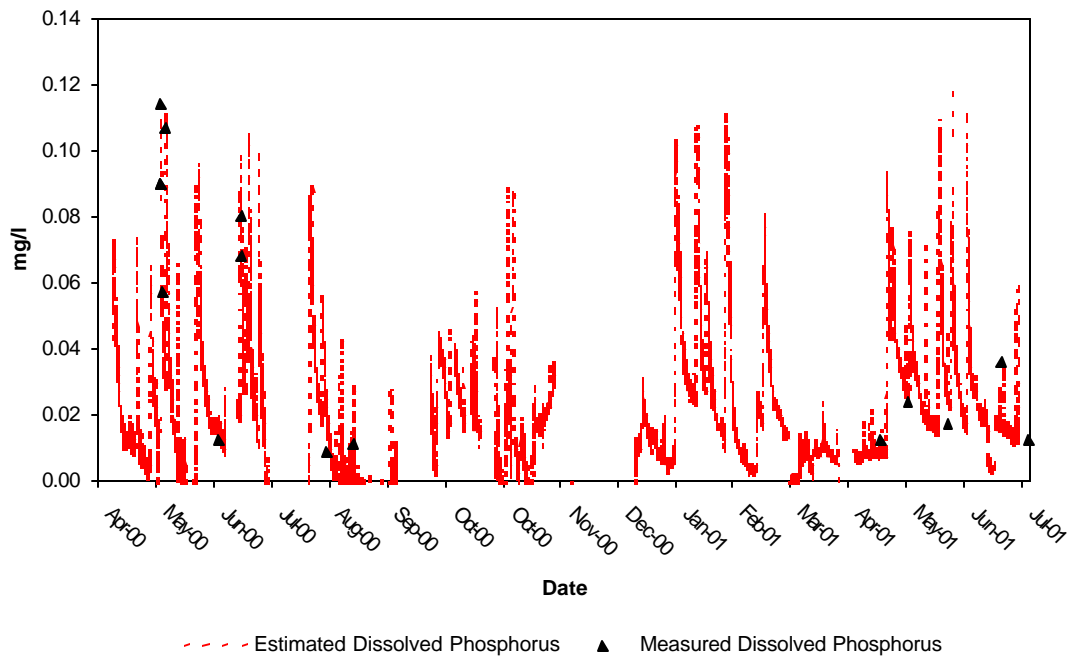


Figure 3.2-28
Comparison of measured and estimated dissolved phosphorus concentration
at Big Creek (near Childers), April 2000 through July 2001.

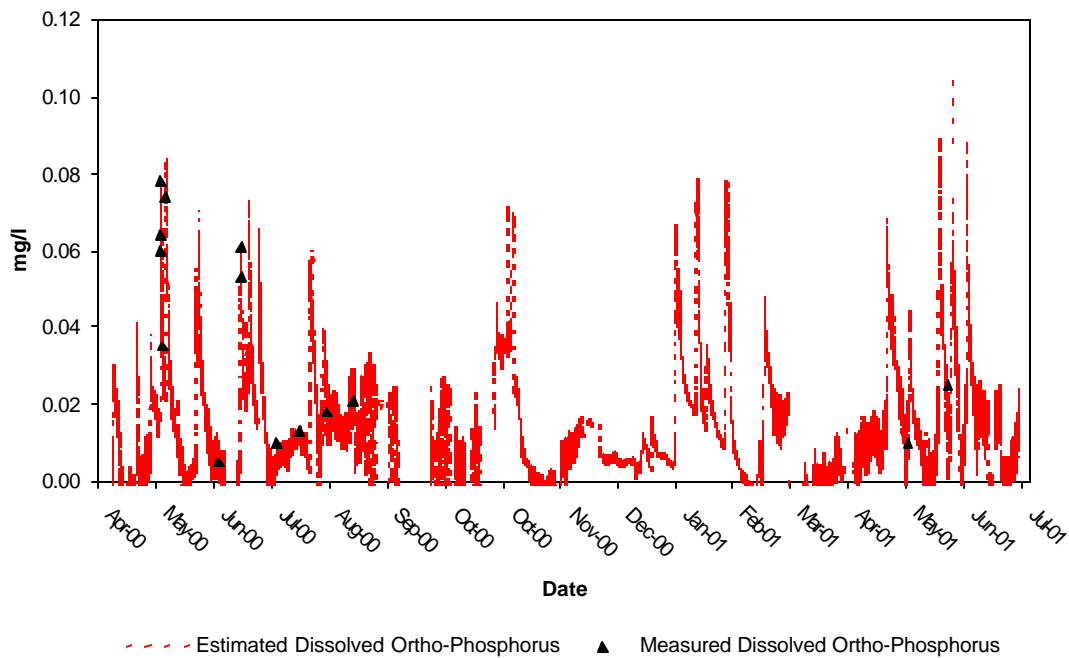


Figure 3.2-29
Comparison of measured and estimated dissolved ortho-phosphorus concentration
at Big Creek (near Childers), April 2000 through July 2001.

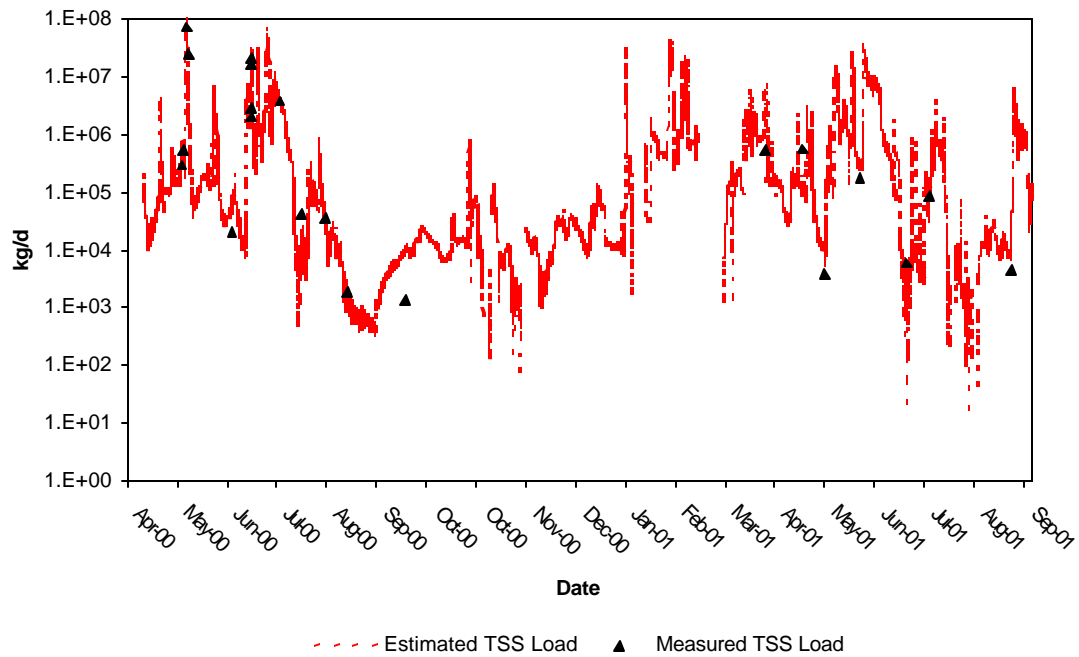


Figure 3.2-30
Comparison of measured and estimated total suspended solids load (kg/d)
at the Verdigris River (Lenapah), April 2000 through September 2001.

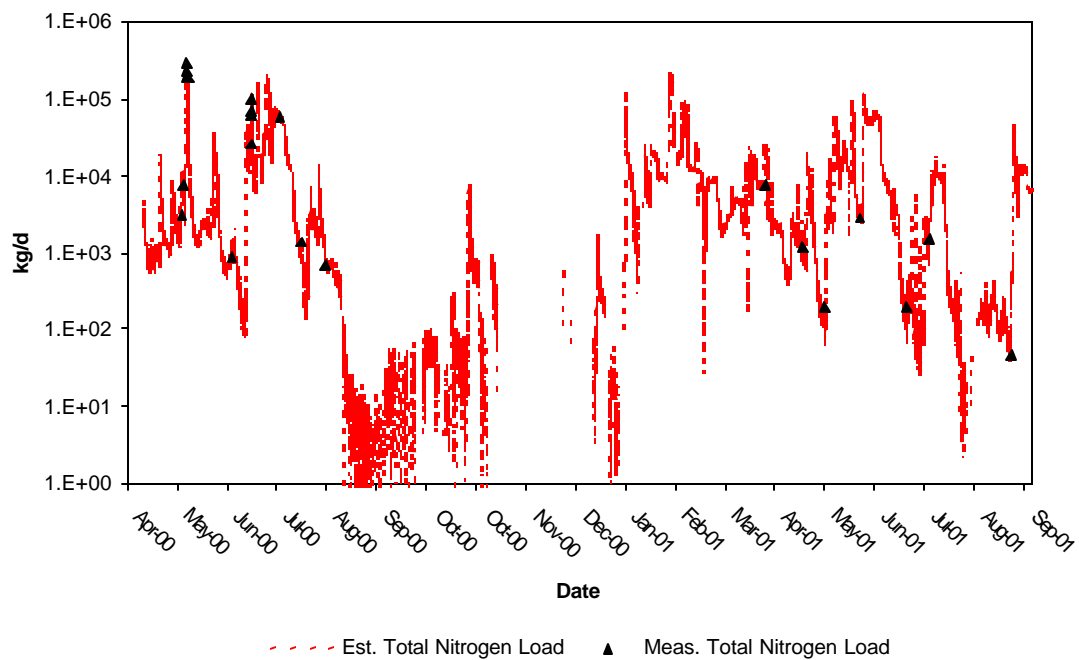


Figure 3.2-31
Comparison of measured and estimated total nitrogen load (kg/d)
at the Verdigris River (Lenapah), April 2000 through September 2001.

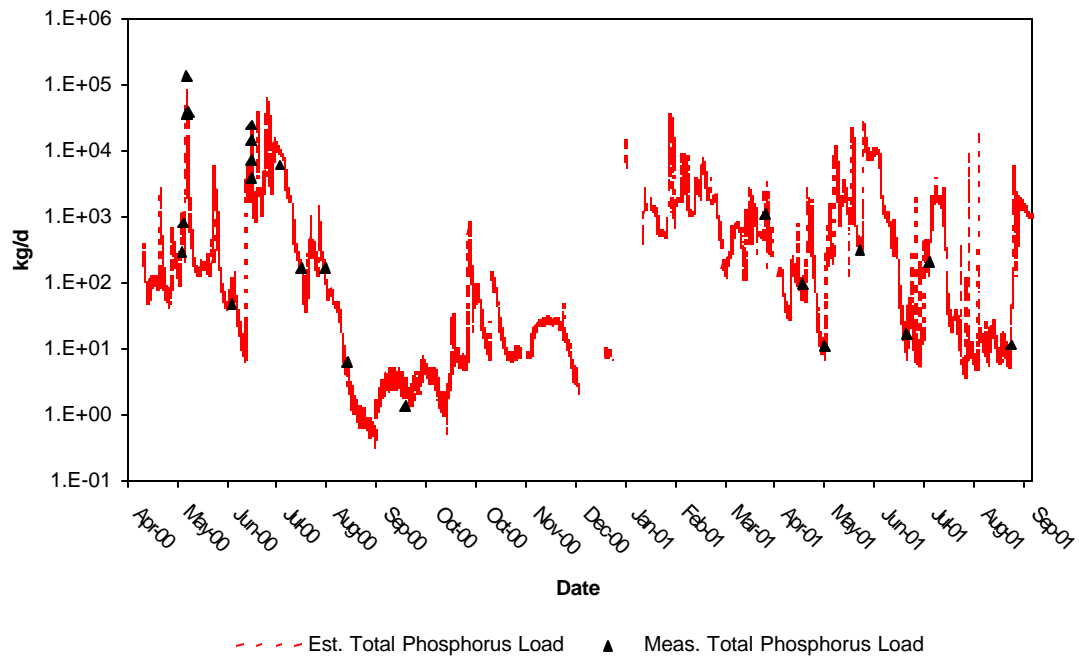


Figure 3.2-32
Comparison of measured and estimated total phosphorus load (kg/d)
at the Verdigris River (Lenapah), April 2000 through September 2001.

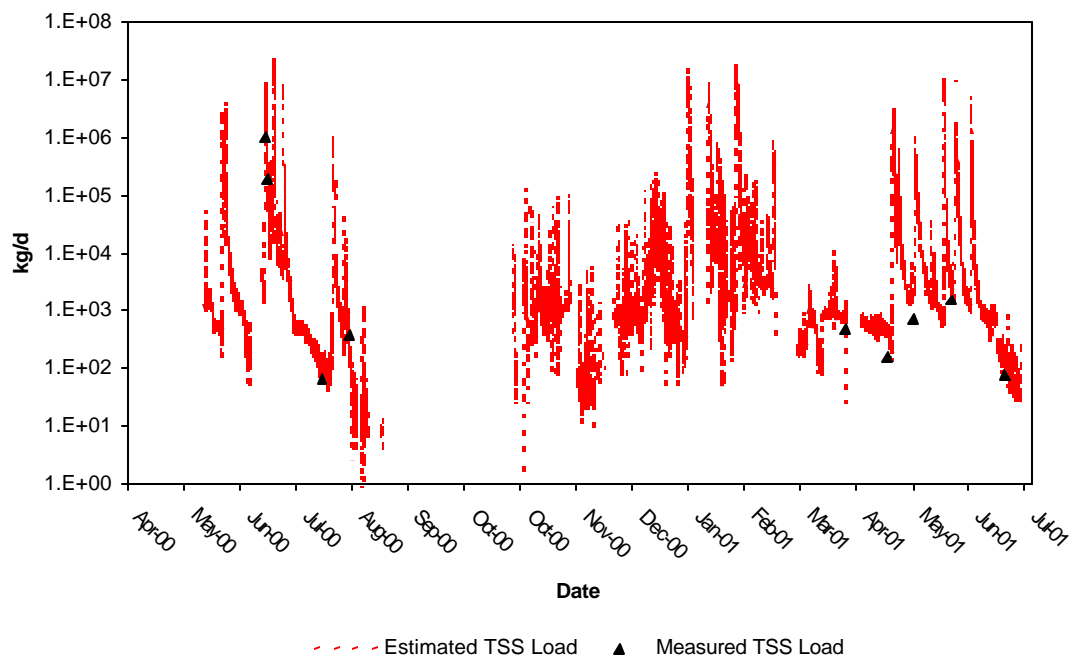


Figure 3.2-33
Comparison of measured and estimated total suspended solids load (kg/d)
at Big Creek (near Childers), April 2000 through July 2001.

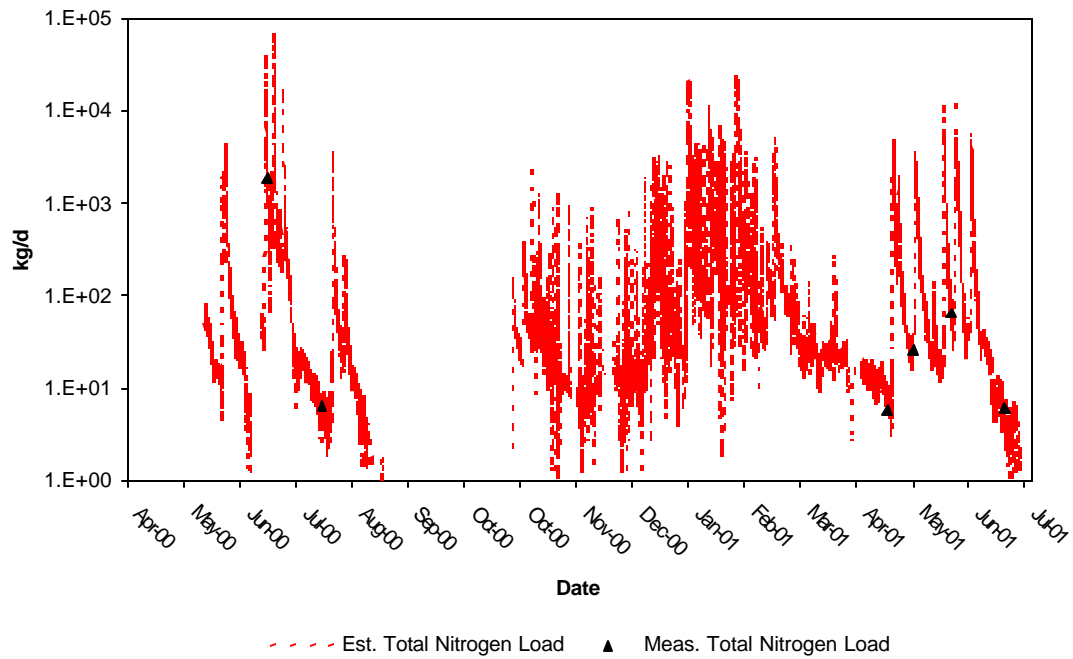


Figure 3.2-34
Comparison of measured and estimated total nitrogen load (kg/d)
at Big Creek (near Childers), April 2000 through July 2001.

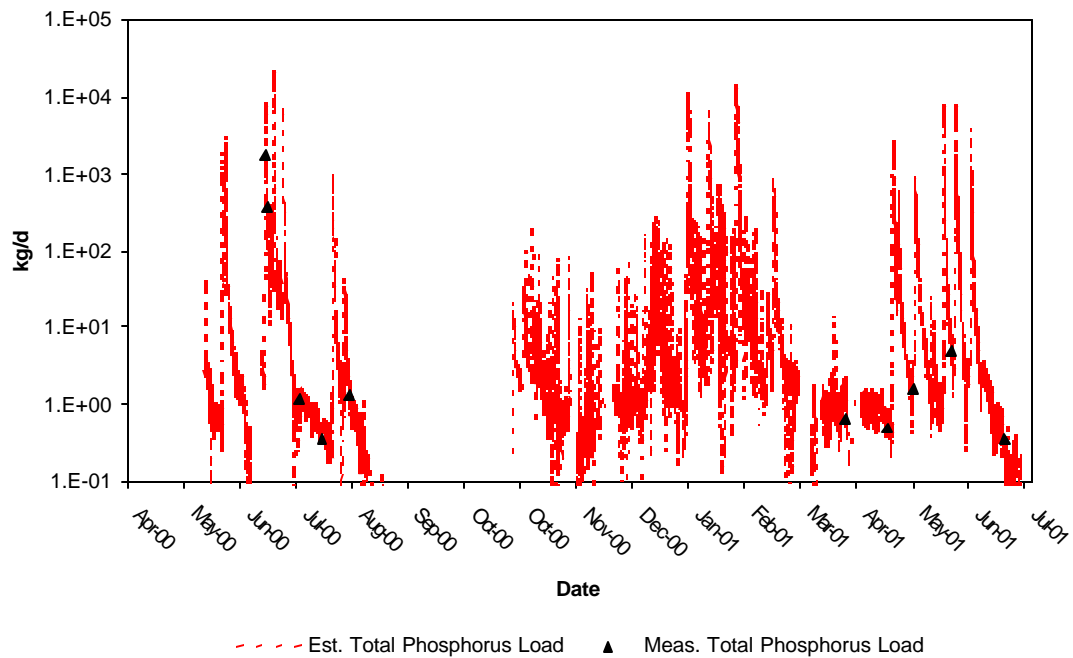


Figure 3.2-35
Comparison of measured and estimated total phosphorus load (kg/d)
at Big Creek (near Childers), April 2000 through July 2001.

3.3 Reservoir Water Quality. Descriptive statistics for most reservoir water quality parameters measured during this study are presented in Table 3.3-1. Results for individual parameters and comparisons between the year I and year II studies are described in detail in the following sections. In general, discussion of water quality results in the following sections will primarily focus on general trends and temporal variability over the April through September study periods throughout 2000 and 2001. Descriptive statistics inclusive of all sampling dates in 2001 are presented in Table 3.3-2.

3.3.1 Nutrients. Concentrations of ammonia (mg/l as N) ranged from < 0.05 mg/l to 0.52 mg/l, with a mean and median concentration of 0.129 mg/l and 0.086 mg/l, respectively, across all sampling sites and dates. Mean and median concentrations were greater by 72.0% and 43.3%, respectively, relative to the 2000 mean and median concentrations of 0.075 mg/l and 0.06 mg/l (Figure 3.3.1-1). Although mean and median ammonia concentrations in 2001 were higher than concentrations in 2000, no significant difference in median ammonia concentration was found between study years at individual sampling sites and sampling depths (Site 1 only). However, whole lake (i.e., sampling sites across all sampling dates and sampling depths) median ammonia concentrations between the 2000 and 2001 were significantly different ($F = 4.46$, $p = 0.039$).

Parameters with which ammonia concentrations were significantly correlated in 2001 include discharge at the Verdigris River gaging station ($r = -0.370$, $p = 0.089$) and the Oologah Dam ($r = -0.388$, $p = 0.041$), total suspended solids ($r = -0.434$, $p = 0.027$), chloride ($r = -0.421$, $p = 0.026$), and sulfate ($r = -0.439$, $p = 0.068$). It is noteworthy that ammonia concentrations were significantly positively correlated in 2000 ($r = 0.643$, $p < 0.001$), while in 2001 concentrations were significantly negatively correlated with discharge at the Verdigris River gaging station. Differences in inflows from the Verdigris River and the hydraulic residence times between the two study periods (195 days in 2000 versus 450 days in 2001 for the period 1 April through 30 September) indicate the potential for autochthonous ammonia loading through ammonification of organic nitrogen by littoral flora (i.e., phytoplankton) and deamination of organic sediments.

**Table 3.3-1. Descriptive statistics for water quality parameters, all sites and dates,
Oologah Lake, Oklahoma, April through September 2001.**

Parameter	Median	Mean	Min	Max	N	# BDL
Alkalinity, Total (mg/l as CaCO ₃)	110.0	116.7	98.0	160.0	28	0
Aluminum, Dissolved (mg/l)	1.0	1.202	0.290	3.40	15	0
Aluminum, Total (mg/l)	2.40	3.481	0.650	13.0	15	0
Antimony, Dissolved (mg/l)			< 0.005		15	15
Antimony, Total (mg/l)			< 0.005		15	15
Arsenic, Dissolved (mg/l)	0.002	0.002	< 0.002	0.002	15	5
Arsenic, Total (mg/l)	0.002	0.003	0.002	0.004	15	1
Barium, Dissolved (mg/l)	0.059	0.088	0.05	0.49	15	0
Barium, Total (mg/l)	0.068	0.076	0.05	0.12	15	15
Beryllium, Dissolved (mg/l)			< 0.002		15	15
Beryllium, Total (mg/l)			< 0.002		15	15
BOD ₅ (mg/l)			< 2.0	2.3	27	26
Cadmium, Dissolved (mg/l)	0.0032	0.0030	< 0.004	0.004	15	10
Cadmium, Total (mg/l)	0.005	0.005	< 0.004	0.006	15	12
Calcium, Dissolved (mg/l)	43.0	42.7	33.0	52.0	15	0
Calcium, Total (mg/l)	43.0	44.1	34.0	58.0	15	0
Chlorophyll a (µg/L)	6.9	7.7	1.2	25.6	43	0
Carbon, Organic, Dissolved (mg/l)	4.2	4.4	3.8	6.4	42	0
Carbon, Organic, Total (mg/l)	4.2	4.7	3.4	7.7	43	0
Chloride (mg/l)	14.0	13.9	11.0	19.0	43	0
Chromium, Dissolved (mg/l)			< 0.025		15	15
Chromium, Total (mg/l)			< 0.025		15	15
Copper, Dissolved (mg/l)			< 0.02		15	15
Copper, Total (mg/l)			< 0.02	0.130	15	14
Hardness, Total (mg/l as CaCO ₃)	140.0	148.6	110.0	200.0	28	0
Iron, Dissolved (mg/l)	0.555	0.735	0.032	2.0	28	0
Iron, Total (mg/l)	1.850	2.582	0.380	8.70	28	0
Lead, Dissolved (mg/l)			< 0.002		15	15
Lead, Total (mg/l)	0.004	0.004	< 0.002	0.006	15	9
Magnesium, Dissolved (mg/l)	7.7	7.6	5.8	9.3	15	0
Magnesium, Total (mg/l)	8.2	8.4	6.6	12.0	15	0
Manganese, Dissolved (mg/l)	0.023	0.024	< 0.02	0.027	15	10
Manganese, Total (mg/l)	0.064	0.084	< 0.02	0.27	28	4
Mercury, Dissolved (mg/l)			< 0.0002		15	15
Mercury, Total (mg/l)	0.0003	0.0003	< 0.0002	0.0003	15	12
Nickel, Dissolved (mg/l)			< 0.02		15	15
Nickel, Total (mg/l)			< 0.02		15	15
Nitrogen, Ammonia (mg/l)	0.086	0.129	< 0.05	0.52	43	22

Table 3.3-1 (Continued)

Parameter	Median	Mean	Min	Max	N	# BDL
Nitrogen, Dissolved Kjeldahl (mg/l)	0.510	0.573	< 0.21	1.30	43	6
Nitrogen, Total Kjeldahl (mg/l)	0.630	0.736	< 0.21	2.66	43	4
Nitrogen, Nitrate-Nitrite (mg/l)	0.42	0.45	0.029	0.98	43	7
Dissolved Oxygen (mg/l)*	6.8	8.0	0.1	9.5	562	0
pH (standard units)*	8.09	-	7.05	8.67	562	0
Phosphorous, Ortho, Dissolved (mg/l)	0.044	0.046	0.01	0.12	43	3
Phosphorous, Dissolved, Total (mg/l)	0.058	0.056	0.012	0.15	43	1
Phosphorous, Total (mg/l)	0.076	0.098	0.02	0.30	43	0
Potassium, Dissolved (mg/l)	2.90	2.96	2.7	3.4	15	0
Potassium, Total (mg/l)	3.4	3.59	2.8	4.5	15	0
Selenium, Dissolved (mg/l)			< 0.002		15	15
Selenium, Total (mg/l)			< 0.002		15	15
Silicon, Dissolved (mg/l)	5.20	5.07	2.3	8.6	15	0
Silicon, Total (mg/l)	9.0	9.5	2.9	25.0	15	0
Silver, Dissolved (mg/l)			< 0.003		15	15
Silver, Total (mg/l)			< 0.003		15	15
Sodium, Dissolved (mg/l)	11.0	11.4	9.5	14.0	15	0
Sodium, Total (mg/l)	15.0	15.1	13.0	18.0	15	0
Secchi Depth (m)*	0.38	0.45	0.09	1.15	43	0
Specific Conductance (uS/cm)*	324.0	328.2	277.0	444.0	562	0
Solids, Settable (mg/l)			< 0.10		28	28
Solids, Dissolved, Total (mg/l)	225.0	238.2	170.0	420.0	28	0
Solids, Suspended, Total (mg/l)	17.0	33.6	< 4.0	220.0	43	2
Solids, Suspended, Volatile (mg/l)	7.5	10.4	< 4.0	34.0	15	0
Sulfate (mg/l)	35.3	34.2	10.1	52.7	28	0
Thallium, Dissolved (mg/l)			< 0.002		15	15
Thallium, Total (mg/l)			< 0.002		15	15
Turbidity*, Field	42.6	53.9	4.1	425.0	558	0
Turbidity, Laboratory (NTU)	37.0	51.14	8.9	200.0	28	0
Light attenuation coefficient*						
Water Temperature (°C)*	25.86	25.14	16.18	31.79	562	0
Zinc, Dissolved (mg/l)			< 0.02	0.031	15	14
Zinc, Total (mg/l)	0.03	0.03	< 0.02	0.05	15	5

* Denotes field parameters.

Table 3.3-2. Descriptive statistics for water quality parameters, all sites and dates, Oologah Lake, Oklahoma, April 2000 through November 2001.

Parameter	Median	Mean	Min	Max
Alkalinity, Total (mg/l as CaCO ₃)	110.0	112.4	87.0	160.0
Aluminum, Dissolved (mg/l)	1.5	1.61	0.29	4.40
Aluminum, Total (mg/l)	2.90	3.47	0.65	13.0
Antimony, Dissolved (mg/l)			< 0.005	
Antimony, Total (mg/l)			< 0.005	
Arsenic, Dissolved (mg/l)			< 0.002	0.002
Arsenic, Total (mg/l)			< 0.002	0.004
Barium, Dissolved (mg/l)	0.06	0.07	0.04	0.49
Barium, Total (mg/l)	0.07	0.07	0.05	0.12
Beryllium, Dissolved (mg/l)			< 0.002	
Beryllium, Total (mg/l)			< 0.002	
BOD ₅ (mg/l)			< 2.0	2.3
Cadmium, Dissolved (mg/l)			< 0.004	0.004
Cadmium, Total (mg/l)			< 0.004	0.006
Calcium, Dissolved (mg/l)	42.0	40.2	30.0	52.0
Calcium, Total (mg/l)	43.0	42.9	34.0	58.0
Chlorophyll a (µg/L)	3.0	5.4	0.3	47.4
Carbon, Organic, Dissolved (mg/l)	4.2	4.5	3.8	6.4
Carbon, Organic, Total (mg/l)	4.2	4.7	3.4	7.7
Chloride (mg/l)	14.0	14.1	11.0	19.0
Chromium, Dissolved (mg/l)			< 0.025	
Chromium, Total (mg/l)			< 0.025	
Copper, Dissolved (mg/l)			< 0.02	
Copper, Total (mg/l)			< 0.02	0.130
Hardness, Total (mg/l as CaCO ₃)	140.0	145.6	110.0	200.0
Iron, Dissolved (mg/l)	0.67	0.87	0.032	2.4
Iron, Total (mg/l)	2.2	2.7	0.38	8.70
Lead, Dissolved (mg/l)			< 0.002	
Lead, Total (mg/l)			< 0.002	0.006
Magnesium, Dissolved (mg/l)	7.6	7.2	4.8	9.3
Magnesium, Total (mg/l)	8.2	8.1	6.5	12.0
Manganese, Dissolved (mg/l)	0.03	0.12	< 0.02	0.069
Manganese, Total (mg/l)	0.07	0.12	< 0.02	0.74
Mercury, Dissolved (mg/l)			< 0.0002	
Mercury, Total (mg/l)			< 0.0002	0.0003
Nickel, Dissolved (mg/l)			< 0.02	
Nickel, Total (mg/l)			< 0.02	
Nitrogen, Ammonia (mg/l)	0.12	0.15	< 0.05	0.52

Table 3.3-2 (continued)

Parameter	Median	Mean	Min	Max
Nitrogen, Dissolved Kjeldahl (mg/l)	0.56	0.6	< 0.21	1.5
Nitrogen, Total Kjeldahl (mg/l)	0.66	0.75	< 0.21	2.66
Nitrogen, Nitrate-Nitrite (mg/l)	0.47	0.49	0.029	0.99
Dissolved Oxygen (mg/l)*	6.8	8.0	0.1	9.5
pH (standard units)*	7.92	8.04	7.05	8.67
Phosphorous, Ortho, Dissolved (mg/l)	0.05	0.05	< 0.01	0.15
Phosphorous, Dissolved, Total (mg/l)	0.06	0.06	< 0.01	0.17
Phosphorous, Total (mg/l)	0.076	0.098	0.02	0.30
Potassium, Dissolved (mg/l)	3.0	3.1	2.6	3.6
Potassium, Total (mg/l)	3.5	3.6	2.8	4.5
Selenium, Dissolved (mg/l)			< 0.002	
Selenium, Total (mg/l)			< 0.002	
Silicon, Dissolved (mg/l)	5.5	5.6	2.0	9.9
Silicon, Total (mg/l)	9.1	9.6	2.0	25.0
Silver, Dissolved (mg/l)			< 0.003	
Silver, Total (mg/l)			< 0.003	
Sodium, Dissolved (mg/l)	11.0	10.8	8.2	14.0
Sodium, Total (mg/l)	14.0	14.5	12.0	18.0
Specific Conductance (uS/cm)*	324.0	328.2	277.0	444.0
Solids, Settable (mg/l)			< 0.10	
Solids, Dissolved, Total (mg/l)	230.0	236.8	170.0	420.0
Solids, Suspended, Total (mg/l)	17.0	30.94	< 4.0	220.0
Solids, Suspended, Volatile (mg/l)	6.4	8.8	< 4.0	34.0
Sulfate (mg/l)	36.7	35.4	10.1	52.7
Thallium, Dissolved (mg/l)			< 0.002	
Thallium, Total (mg/l)			< 0.002	
Turbidity*,Field	46.8	59.9	4.1	510.6
Turbidity, Laboratory (NTU)	41.0	52.43	8.9	200.0
Water Temperature (°C)*	25.43	23.13	6.6	31.79
Zinc, Dissolved (mg/l)			< 0.02	0.031
Zinc, Total (mg/l)	0.03	0.03	< 0.02	0.06

* Denotes field parameters.

Nitrite + nitrate (mg/l) concentrations across all sampling sites and sampling dates ranged from 0.029 mg/l to 0.98 mg/l, with a mean and median concentration of 0.45 mg/l and 0.42 mg/l, respectively. Relative to the 2000 study, mean and median concentrations were 59.6% and 28.0% greater in 2001 relative to the mean and median nitrite + nitrate concentrations of 0.282 mg/l and 0.328 mg/l present in 2000. Whole lake (i.e., sampling sites across all sampling dates and sampling depths) median concentrations between the 2000 and 2001 study periods were significantly different ($F = 3.86$, $p = 0.058$). Nitrite + nitrate concentrations among stations exhibited an equal amount of variability, and no significant differences were found. Seasonal dynamics were readily apparent with concentrations highest in the spring and early summer and decreasing through the late summer and fall. It was also found that concentrations among sampling dates were significantly different ($F = 55.03$, $p < 0.001$), and the 2001 sampling dates separated into three statistically distinct groups: $A > B > C$ (Figure 3.3.1-2).

During the 2001 sampling period, nitrite + nitrate was significantly correlated with river discharge at the Verdigris River gaging station ($r = 0.619$, $p < 0.001$), discharge from the reservoir ($r = 0.418$, $p = 0.001$), Secchi depth ($r = -0.978$, $p = 0.023$), chlorophyll *a* ($r = -0.417$, $p = 0.011$), water temperature ($r = -0.714$, $p < 0.001$), total phosphorus ($r = 0.400$, $p = 0.007$), dissolved total phosphorus ($r = 0.424$, $p = 0.005$), ortho-phosphorus ($r = 0.638$, $p < 0.001$), total magnesium ($r = -0.744$, $p = 0.001$), dissolved magnesium ($r = -0.749$, $p = 0.008$), total chloride ($r = 0.361$, $p = 0.016$), sulfate ($r = 0.657$, $p < 0.001$), total iron ($r = 0.398$, $p = 0.022$), dissolved iron ($r = 0.735$, $p < 0.001$), dissolved manganese ($r = -0.722$, $p = 0.005$), total aluminum ($r = 0.428$, $p < 0.086$), dissolved aluminum ($r = 0.739$, $p = 0.001$), total silicon ($r = 0.693$, $p = 0.002$), dissolved silicon ($r = 0.815$, $p < 0.001$), total dissolved solids ($r = 0.441$, $p = 0.010$), and turbidity ($r = 0.313$, $p = 0.076$).

In comparison, during the 2000 study period many of the parameters listed above were either not significantly correlated or if significantly correlated the coefficient of determination was smaller (i.e., the correlations were not as strong).

For example, in 2000, nitrite + nitrate was not significantly correlated with total and dissolved total phosphorus, total iron, total and dissolved aluminum, or total and dissolved silicon. The significant correlation observed with iron, manganese, aluminum, and silicon lend strength to the hypothesis that advective transport plays a substantial and important role in macro- and micronutrient availability within the Oologah system.

As in the 2000 study, Kjeldahl nitrogen analyses for this study included both total Kjeldahl nitrogen (TKN) and dissolved Kjeldahl nitrogen (DKN). Concentrations of TKN ranged from < 0.21 mg/l to 2.66 mg/l across all sampling sites and sampling dates. Mean and median TKN concentrations were 0.736 mg/l and 0.630 mg/l, respectively. Mean concentrations of TKN were 3.5% lower and median TKN concentrations were 2.3% greater than mean and median TKN concentrations present in 2000. Overall, whole lake median TKN concentrations between the study years did not differ significantly, and no significant difference was found in median concentrations at individual sampling sites and depths between study years.

The spatial distribution of TKN within the reservoir was similar to that observed during the 2000 study, with significantly higher concentrations ($F = 4.03$, $p = 0.008$) and greater variability present at Sites 4 and 5 relative to Sites 1, 2, and 3 (Figure 3.3.1-3). At Site 1, median TKN concentrations at 1 meter above the bottom were significantly greater than surface concentrations ($F = 4.07$, $p = 0.066$) and exhibited a greater degree of variability. Seasonal dynamics in TKN concentration do not appear to show any distinct trend with only two sampling dates (31 July 2001 and 4 September 2001) significantly different from the other 2001 sampling dates ($F = 2.61$, $p = 0.023$) (Figure 3.3.1-4). Periods of greater variability and median whole lake concentrations appear to be associated with periods of increased inflows or outflows although no direct correlation between inflows and TKN concentration was observed.

Significant correlations were identified between TKN and Secchi depth ($r = -0.720$, $p < 0.001$), chlorophyll *a* ($r = 0.273$, $p = 0.093$), water temperature ($r = -0.283$, $p = 0.062$), pH ($r = -0.426$, $p = 0.004$), alkalinity ($r = 0.423$, $p = 0.013$), total suspended solids ($r = 0.696$, $p < 0.001$), volatile suspended solids ($r = 0.599$, $p = 0.007$), total phosphorus ($r = 0.711$, $p < 0.001$), dissolved total phosphorus ($r = 0.504$, $p < 0.001$), ortho-phosphorus ($r = 0.266$,

$p = 0.081$), hardness ($r = 0.460$, $p = 0.006$), total potassium ($r = 0.863$, $p < 0.001$), total iron ($r = 0.808$, $p < 0.001$), total manganese ($r = 0.466$, $p = 0.013$), total aluminum ($r = 0.930$, $p < 0.001$), dissolved aluminum ($r = 0.730$, $p = 0.001$), total silicon ($r = 0.930$, $p < 0.001$), dissolved silicon ($r = 0.595$, $p = 0.009$), and turbidity ($r = 0.864$, $p < 0.001$).

Concentrations of DKN ranged from < 0.21 mg/l to 1.30 mg/l, with a mean and median concentration of 0.573 mg/l and 0.510 mg/l, respectively. Mean and median DKN concentrations were 9.0% greater and 17.2% lower, respectively, than mean and median concentrations present in 2000. In 2001, the percentage of DKN comprised 78.0% of the TKN across all surface sampling sites and dates. At 1 m above the bottom (Site 1 only), DKN comprised 83.9% of the TKN. Both the trend as well as the DKN:TKN proportions are similar to those observed during the 2000 study period, with no significant difference observed in median DKN concentrations between the two studies. Spatially, no significant difference was found between study periods at individual sampling sites or between stations during 2001 only. There were significant differences observed seasonally ($F = 11.91$, $p < 0.001$) with sampling dates falling into two distinct groups ($A > B$); however, no distinctive seasonal trend was evident across the study periods (Figure 3.3.1-5).

Significant correlations were identified between DKN and discharge from the dam ($r = 0.351$, $p = 0.019$), Secchi depth ($r = -0.284$, $p = 0.088$), pH ($r = -0.454$, $p = 0.002$), dissolved magnesium ($r = -0.572$, $p = 0.066$), total chloride ($r = 0.330$, $p = 0.029$), total iron ($r = 0.491$, $p = 0.004$), dissolved manganese ($r = -0.604$, $p = 0.049$), total aluminum ($r = 0.499$, $p = 0.035$), dissolved aluminum ($r = 0.556$, $p = 0.017$), total silicon ($r = 0.642$, $p = 0.004$), dissolved silicon ($r = 0.599$, $p = 0.009$), and turbidity ($r = 0.438$, $p = 0.011$).

Total phosphorus (TP) ranged from 0.02 mg/l to 0.30 mg/l, with a mean and median concentration of 0.098 mg/l and 0.076 mg/l, respectively. Mean and median TP concentrations were 11.1% and 8.4% lower, but not significantly different ($F = 0.21$, $p = 0.645$) in 2001 relative to concentrations present in the reservoir during the 2000 study. The horizontal and vertical distribution of TP in the reservoir was similar to the pattern observed in 2000. As in 2000, TP concentrations at Site 1 were significantly higher at 1 m above the bottom ($F = 11.93$, $p = 0.003$)

than at 1 m below the surface. Also, TP concentrations were found in higher concentrations and generally exhibited greater variability at sampling sites above Winganon Bridge when compared to sampling sites below Winganon Bridge (Figure 3.3.1-6), with only two significantly distinct groups identified ($F = 7.76$, $p < 0.001$). While median TP concentrations generally did not differ from one sampling trip to the next, they did exhibit noticeable temporal variability over the 2-year sampling period (Figure 3.3.1-7), and during the 2001 study a significant difference was found among sampling dates ($F = 2.52$, $p = 0.024$).

Total phosphorus was significantly correlated with discharge at the Verdigris River gaging station ($r = 0.300$, $p = 0.031$), Secchi depth ($r = -0.892$, $p < 0.001$), chlorophyll *a* ($r = 0.276$, $p = 0.073$), water temperature ($r = -0.545$, $p < 0.001$), pH ($r = -0.340$, $p = 0.016$), total suspended solids ($r = 0.798$, $p < 0.001$), volatile suspended solids ($r = 0.792$, $p < 0.001$), total Kjeldahl nitrogen ($r = 0.711$, $p < 0.001$), nitrite + nitrate ($r = 0.400$, $p = 0.007$), ortho-phosphorus ($r = 0.666$, $p < 0.001$), total organic carbon ($r = 0.247$, $p = 0.077$), dissolved organic carbon ($r = 0.360$, $p = 0.009$), total hardness ($r = 0.339$, $p = 0.050$), total magnesium ($r = 0.476$, $p = 0.046$), total potassium ($r = 0.862$, $p < 0.001$), total iron ($r = 0.940$, $p < 0.001$), dissolved iron ($r = 0.565$, $p < 0.001$), total manganese ($r = 0.646$, $p < 0.001$), total aluminum ($r = 0.925$, $p < 0.001$), dissolved aluminum ($r = 0.787$, $p < 0.001$), total silicon ($r = 0.916$, $p < 0.001$), dissolved silicon ($r = 0.640$, $p = 0.004$), and laboratory turbidity ($r = 0.924$, $p < 0.001$).

Concentrations of dissolved total phosphorus (d TP) ranged from 0.012 mg/l to 0.15 mg/l, with a mean and median concentration of 0.056 mg/l and 0.058 mg/l, respectively. Mean and median d TP concentrations increased by 7.7% and 20.8%, respectively, over concentrations present in the reservoir in 2000. However, this increase in d TP concentration was not statistically significant. At individual sampling sites, no significant difference was found between study periods. At Site 1, no significant difference was observed between surface and bottom concentrations. Trends in d TP concentrations were similar to those observed in 2000 with bottom concentrations significantly higher ($F = 10.74$, $p = 0.005$) and more variable than concentrations at 1 m below the surface (Figure 3.3.1-8).

When data were plotted to examine differences in the horizontal distribution of d TP, no distinct trend was evident with no significant difference among stations observed. While no significant difference was detected between sampling sites in d TP during the 2000 study, a trend of increasing concentrations in the up-reservoir direction was evident (USACE 2001). Comparisons between the 2000 and 2001 study periods indicate the magnitude of d TP variability at individual stations was the same or greater, and the trend of increasing concentration in the up-reservoir direction was not as evident due to greater overall variability at the individual stations (Figure 3.3.1-9) in 2001 relative to 2000. There was a significant difference among sampling dates in d TP concentrations ($F = 5.31$, $p < 0.001$) during the 2001 study. Dissolved total phosphorus also shows a distinct seasonal trend with increased concentrations present throughout the fall and spring and decreased concentrations present throughout the summer and early fall months (Figure 3.3.1-10).

Parameters that were significantly correlated with dissolved total phosphorus include Secchi depth ($r = -0.651$, $p < 0.001$), water temperature ($r = -0.666$, $p < 0.001$), pH ($r = -0.374$, $p < 0.008$), total suspended solids ($r = 0.458$, $p = 0.001$), total Kjeldahl nitrogen ($r = 0.504$, $p < 0.001$), nitrite + nitrate ($r = 0.424$, $p = 0.004$), ortho-phosphorus ($r = 0.748$, $p < 0.001$), total magnesium ($r = 0.510$, $p = 0.036$), total potassium ($r = 0.591$, $p = 0.013$), total iron ($r = 0.671$, $p < 0.001$), dissolved iron ($r = 0.733$, $p < 0.001$), total aluminum ($r = 0.594$, $p = 0.012$), dissolved aluminum ($r = 0.831$, $p < 0.001$), total silicon ($r = 0.756$, $p < 0.001$), dissolved silicon ($r = 0.810$, $p < 0.001$), and laboratory turbidity ($r = 0.592$, $p < 0.001$).

During this study period, dissolved ortho-phosphorus (OP) concentrations ranged from 0.01 mg/l to 0.12 mg/l, with a mean and median concentration of 0.046 mg/l and 0.044 mg/l, respectively. Mean and median concentrations were 15% and 10% greater relative to concentrations observed in 2000, and median OP concentrations between the two study years were significantly different ($F = 3.75$, $p = 0.055$). Horizontally, there was no significant difference in OP concentrations among the sampling sites, and, as in 2000, no spatial trend was evident. At individual sampling sites, no significant differences were found between study periods with the exception of Site 1. At Site 1, the OP concentration was found to be significantly higher in 2001 versus concentrations present in 2000 ($F = 4.26$, $p = 0.026$). In

addition, the vertical distribution of OP was similar to that observed in 2000 at Site 1 with bottom concentrations significantly higher ($F = 10.95$, $p = 0.005$) than surface concentrations. Temporally, there was a significant difference among sampling dates ($F = 4.70$, $p < 0.001$) and two statistically distinct groups were identified ($A \geq B$). In addition, a distinct seasonal trend was evident with greater concentrations present in the reservoir during the summer months (Figure 3.3.1-11).

Dissolved OP was significantly correlated in this study with discharge at the Verdigris River gaging station ($r = 0.303$, $p = 0.034$), discharge from the reservoir at Oologah Dam ($r = 0.443$, $p = 0.001$), Secchi depth ($r = -0.573$, $p < 0.001$), water temperature ($r = -0.669$, $p < 0.001$), specific conductance ($r = 0.398$, $p = 0.006$), pH ($r = -0.339$, $p = 0.020$), total Kjeldahl nitrogen ($r = 0.266$, $p = 0.081$), nitrite + nitrate ($r = 0.638$, $p < 0.001$), total phosphorus ($r = 0.666$, $p < 0.001$), dissolved total phosphorus ($r = 0.784$, $p < 0.001$), total chloride ($r = 0.280$, $p = 0.052$), sulfate ($r = 0.489$, $p = 0.004$), total iron ($r = 0.471$, $p = 0.006$), dissolved iron ($r = 0.739$, $p < 0.001$), dissolved aluminum ($r = 0.676$, $p = 0.003$), total silicon ($r = 0.602$, $p = 0.011$), dissolved silicon ($r = 0.802$, $p < 0.001$), total dissolved solids ($r = 0.607$, $p < 0.001$), and laboratory turbidity ($r = 0.464$, $p = 0.007$).

The nutrient parameters monitored in this study shared significant correlations with many of the same parameters. These parameters are generally correlated with nutrient parameters as a result of biogeochemical cycling as well as algal density and productivity. Higher nitrite + nitrate concentrations present in the reservoir are linked to the higher ammonia concentrations observed during the 2001 study period. Ammonia is converted, through the nitrification process, to nitrite and then to nitrate by bacteria such as *Nitrosomonas* sp. and *Nitrobacter* sp., and once converted becomes bio-available. This direct relationship of ammonia, nitrite, and nitrate with phytoplankton is helpful in explaining the correlations mentioned above. For example, iron and manganese are not only important for nitrate assimilation, iron also plays a role in the enzymatic pathways of chlorophyll and protein synthesis (Wetzel 1983). Aluminum plays an important role with respect to silica in the water column as well. As described in Wetzel (1983), particulate silica is principally found in two forms, a biotic form (e.g., diatoms)

and as silica adsorbed to inorganic particles or organically complexed, the major source of silica being the chemical by-products of aluminosilicate compounds.

Many of the parameters significantly correlated with TKN and DKN also shared a significant correlation with nitrite + nitrate during the study period and are correlated with DKN and TKN for many of the reasons discussed above. The C:N ratios in Oologah Lake also indicate that the majority of organic matter is autochthonous (the majority of which is likely the result of phytoplankton degradation) in nature, with mean C:N ratios of 8.4 in 2000 and 13.35 in 2001. While nitrogen levels in the reservoir are generally sufficient to keep the C:N ratios low, N:P ratios indicate that the limiting nutrient in Oologah is nitrogen with N:P averaging 8.3 in 2001 and ranging from 2.8 to 24.2. Phosphorus concentrations in Oologah Lake are somewhat unusual when compared to other surface waters due to measurable quantities of dissolved orthophosphorus being present throughout the year.

While the chemical data support the hypothesis of nitrogen limitation (when nutrients limit algal growth), the 2000 phytoplankton analysis is mixed. In 2000, an increase in cyanobacteria was observed during periods when the N:P ratio was lower; however, the other groups comprising the phytoplankton assemblage in the reservoir were still represented in relatively high numbers. The influence of nitrogen limitation in Oologah Lake is not well understood at this time, and it is possible that Oologah Lake is not nitrogen limited at all and that the low N:P ratio observed is a product of the turbid nature of the reservoir as well as the associated adsorption of phosphorus to suspended solids.

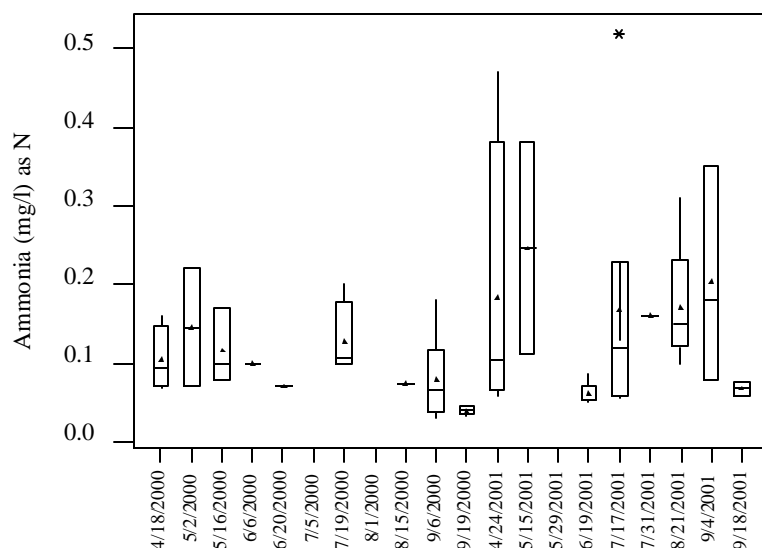


Figure 3.3.1-1
Whole lake ammonia (mg/l) variability in Oologah Lake, Oklahoma, 18 April through 19 September 2000 and 24 April through 18 September 2001.

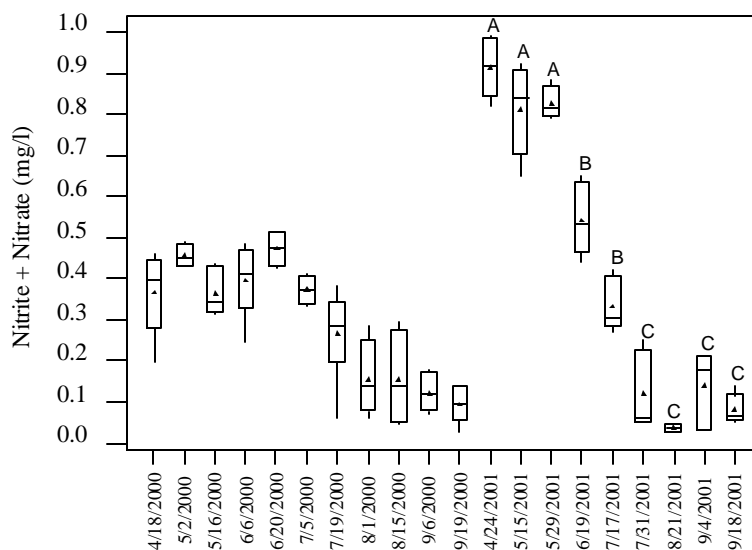


Figure 3.3.1-2
Whole lake nitrite + nitrate (mg/l) variability in Oologah Lake, Oklahoma, 18 April through 19 September 2000 and 24 April through 18 September 2001 (letters identify statistically distinct groups).

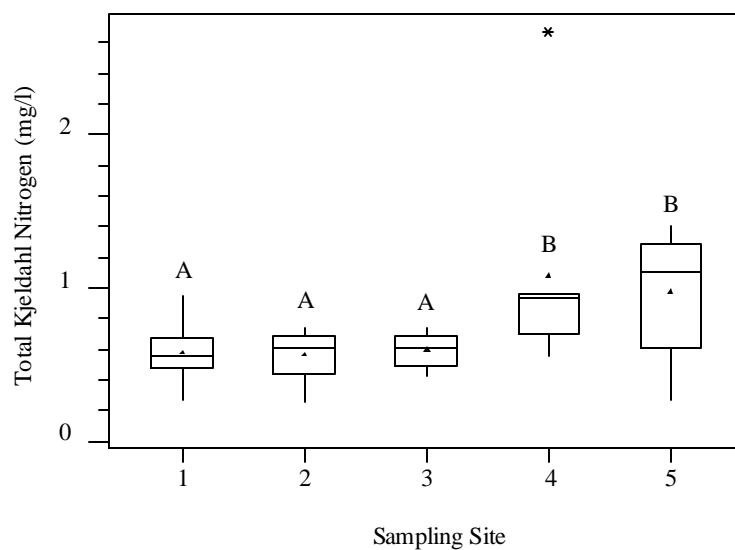


Figure 3.3.1-3
Total Kjeldahl nitrogen (mg/l) variability in Oologah Lake, by station, 24 April through 18 September 2001 (letters identify statistically distinct groups).

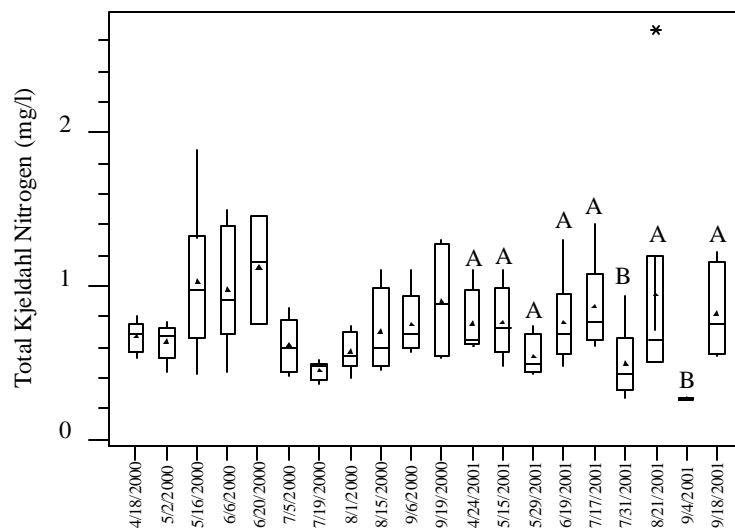


Figure 3.3.1-4
Whole lake total Kjeldahl nitrogen (mg/l) variability in Oologah Lake, by date, 18 April through 19 September 2000 and 24 April through 18 September 2001 (letters identify statistically distinct groups).

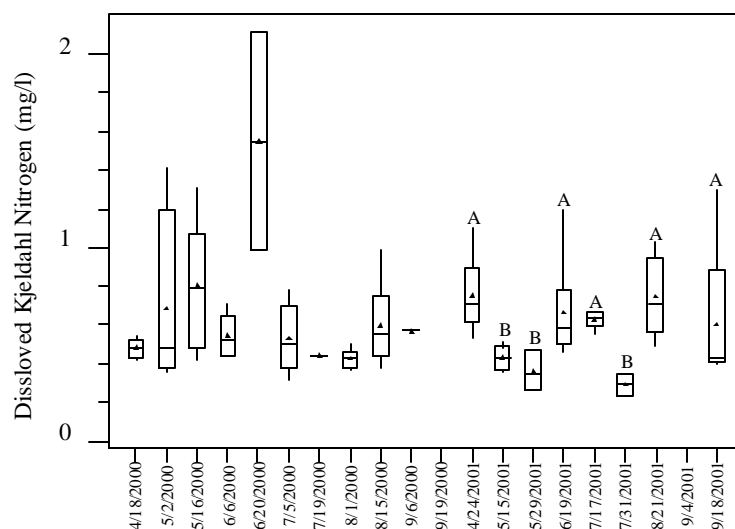


Figure 3.3.1-5
Whole lake dissolved Kjeldahl nitrogen (mg/l) variability in Oologah Lake, by date, 18 April through 19 September 2000 and 24 April through 18 September 2001 (letters identify statistically distinct groups).

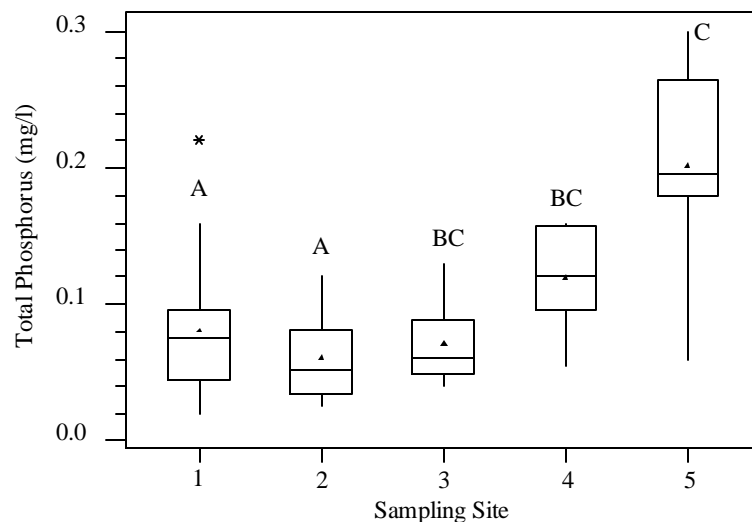


Figure 3.3.1-6
Total phosphorus (mg/l) variability in Oologah Lake, by station, 24 April through 18 September 2001 (letters identify statistically distinct groups).

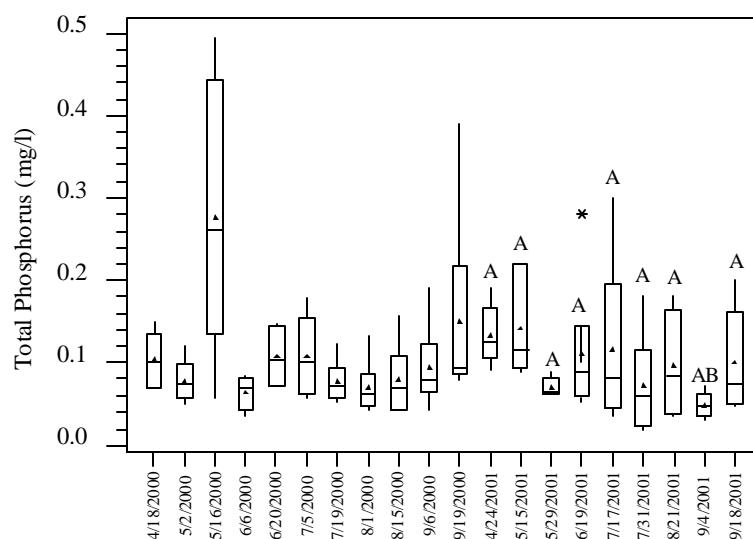


Figure 3.3.1-7
Whole lake total phosphorus (mg/l) variability in Oologah Lake, by date,
18 April through 19 September 2000 and 24 April through 18 September 2001
(letters identify statistically distinct groups).

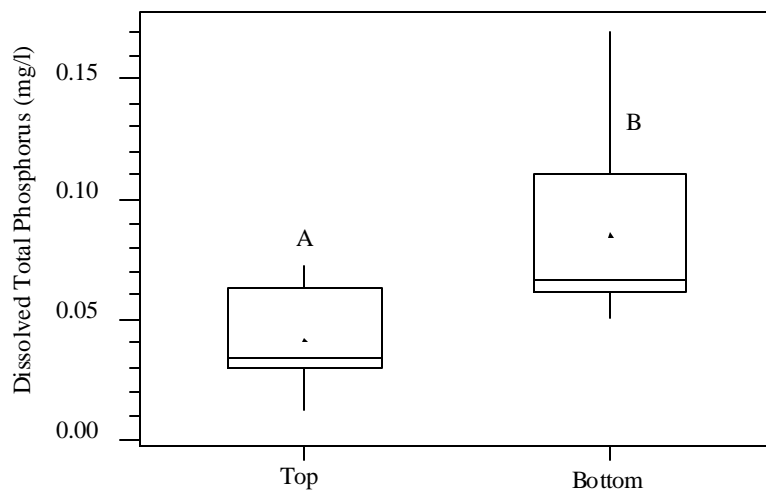


Figure 3.3.1-8
Dissolved total phosphorus (mg/l) variability in Oologah Lake between surface
and bottom samples at Site 1, 24 April through 18 September 2001.
(letters identify statistically distinct groups).

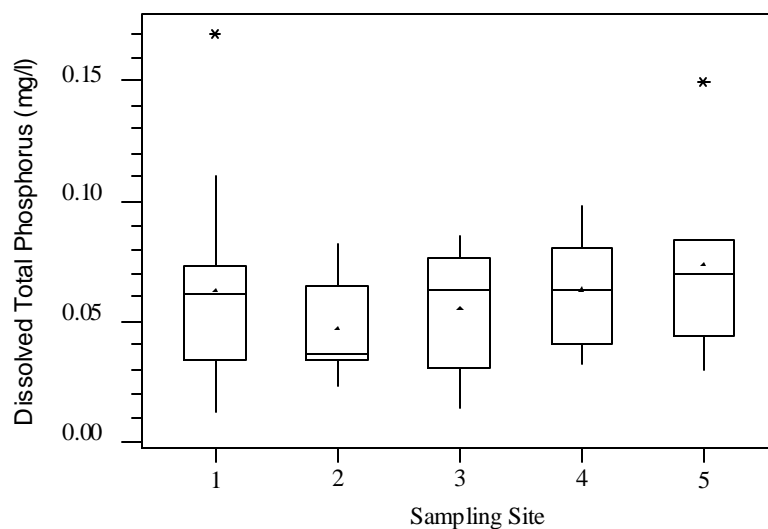


Figure 3.3.1-9
Dissolved total phosphorus (mg/l) variability in Oologah Lake, by station, 24 April through 18 September 2001.

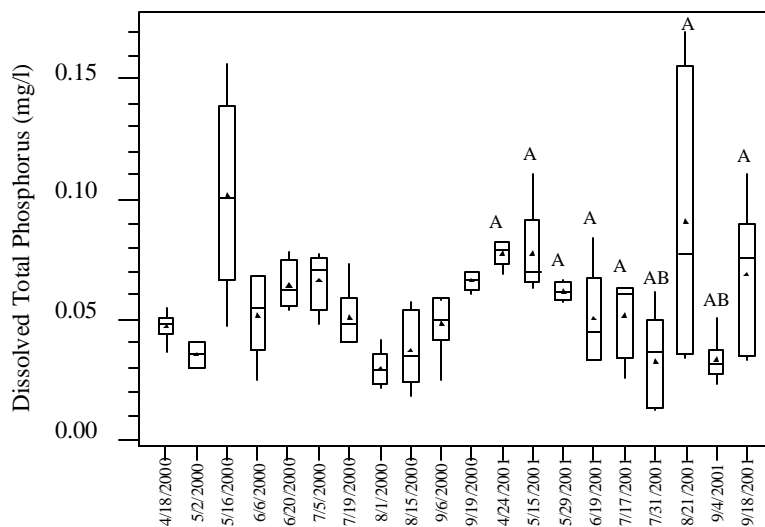


Figure 3.3.1-10
Dissolved total phosphorus (mg/l) in Oologah Lake, by date, 18 April through 19 September 2000 and 24 April through 18 September 2001 (letters identify statistically distinct groups).

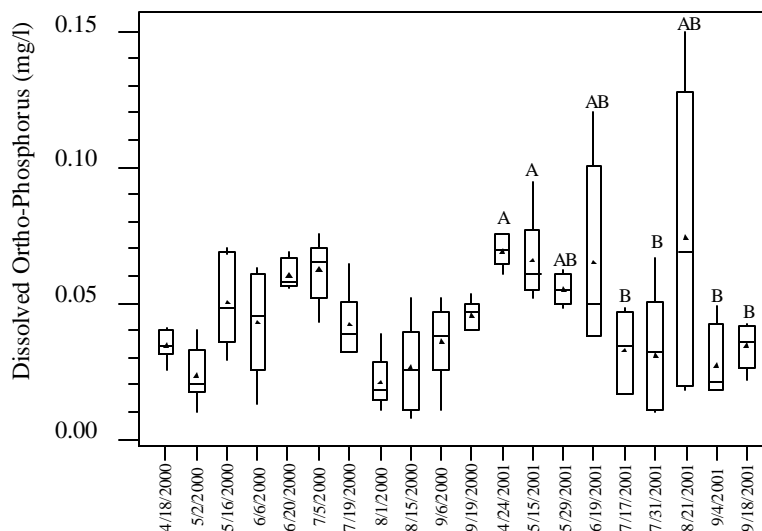


Figure 3.3.1-11
Dissolved ortho-phosphorus (mg/l) in Oologah Lake, by date, 18 April through
19 September 2000 and 24 April through 18 September 2001
(letters identify statistically distinct groups).

3.3.2 Turbidity and Suspended Solids. Settable solids, total dissolved solids, total suspended solids, volatile suspended solids, laboratory turbidity, and field turbidity were sampled at each station on all sampling trips between 18 April 2001 and 19 June 2001. In early July, a review of data collected in 2000 and 2001 was performed. As a result, monitoring of settable solids, total dissolved solids, and volatile suspended solids was discontinued based upon several factors; (1) the parameter was frequently found to be below the quantitation limit, (2) the parameter did not exhibit any discernable degree of spatial and temporal variability, or (3) instruments were available for parameter quantification in the field.

Following this review, monitoring was suspended for settable solids, total dissolved solids, volatile suspended solids, and laboratory turbidity for one or more of the factors mentioned above. Historically, it has been difficult to obtain field samples of turbidity that relate well with values obtained in the laboratory. A regression of field turbidity versus laboratory turbidity was performed to see how closely field turbidity predicted laboratory turbidity. The

regression analysis indicated the two parameters were significantly related ($F = 807.02$, $p < 0.001$, $R^2 = 0.943$) (Figure 3.3.2-1). The descriptive statistics for settleable solids, total dissolved solids, volatile suspended solids, and laboratory turbidity sampled between 18 April and 19 June 2000 are provided in Table 3.3.1-1. The discussion below will include field turbidity and total suspended solids.

Surface field turbidity ($n = 41$) across all sampling sites and dates ranged from 8 NTU to 282.1 NTU, with mean and median values of 62.73 NTU and 49.50 NTU, respectively. Descriptive statistics for all samples and depths ($n = 558$) are provided in Table 3.3.1-1. Mean and median surface turbidity values in 2001 were 9.5% and 7.7% higher relative to surface turbidity values in 2000 (mean, 57.3 NTU and median, 45.9 NTU), but this increase was not statistically significant. Surface turbidity exhibited patterns similar to those observed in 2000. Median turbidity values were highest in the riverine portions of the reservoir (Site 5) and decreased significantly ($F = 9.68$, $p < 0.001$) in the down-reservoir direction with values lowest near the dam (Site 1) (Figure 3.3.2-2). As was observed during the 2000 study, turbidity increased significantly ($F = 6.83$, $p = 0.019$) with depth throughout much of the study period. Figures 3.3.2-3 through 3.3.2-5 illustrate the increase of turbidity with depth over both the 2000 and 2001 study periods for Sites 1, 2, and 3. Above Winganon Bridge (Sites 4 and 5), the reservoir does not exhibit a strong gradient in vertical turbidity. Turbidity also exhibited an observed seasonal trend (Figure 3.3.2-6), and median turbidity was significantly different among sampling dates ($F = 2.19$, $p = 0.048$). However, Tukey's multiple comparison test on ranked data found no significant difference among groups. When temporal differences were re-examined using month as the factor, seasonal turbidity differences were again significant ($F = 2.69$, $p = 0.033$), but the multiple comparison test was unable to discriminate among months.

Total suspended solids (TSS) concentrations during the study period ranged from < 4.0 mg/l to 220.0 mg/l, with mean and median concentrations of 33.6 mg/l and 17.0 mg/l, respectively. The mean TSS concentration was 3.3% higher and the median TSS concentration was 2.3% lower relative to the mean and median concentrations present in 2000. No significant difference in median TSS concentrations was observed between the two study periods. As was the case with turbidity, TSS trends closely mirrored those observed in 2000. Concentrations

were found to be significantly different among sampling sites ($F = 16.38$, $p < 0.001$), with concentrations greatest in the riverine portions of the reservoir and decreasing in a down-reservoir direction. This decrease can be substantial in the portions of the reservoir below Winganon Bridge (Figure 3.3.2-7). At Site 1, median TSS concentrations significantly increased with depth ($F = 30.43$, $p < 0.001$) and were 156% greater at depth relative to surface concentrations (Figure 3.3.2-8).

Concentrations of TSS were not statistically significantly different among dates during the 2001 study period; however, there is slight seasonal flux in whole lake mean and median concentrations apparent over the course of the two study years (Figure 3.3.2-9).

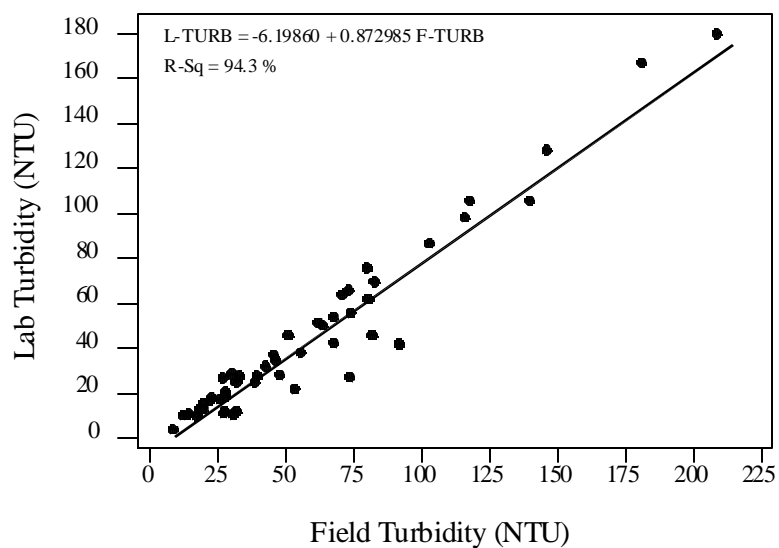


Figure 3.3.2-1
Linear regression of laboratory turbidity (NTU) versus field turbidity (NTU)
for the sampling period 18 April through 19 September 2000.

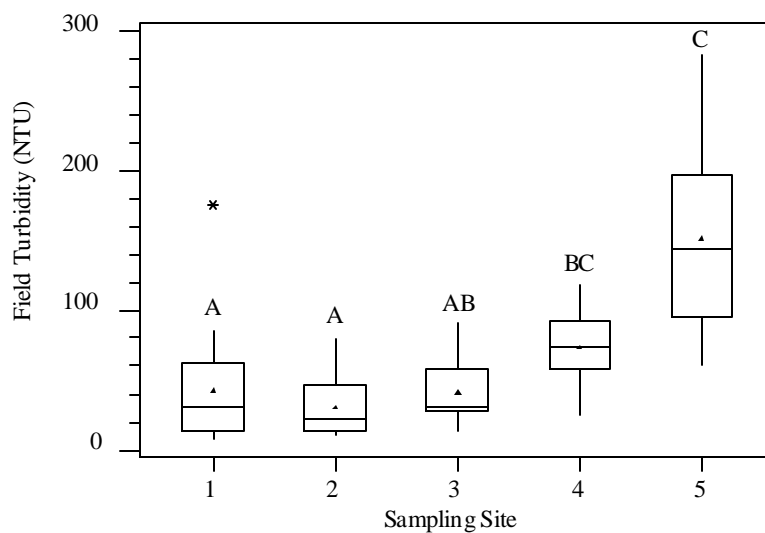


Figure 3.3.2-2
Field turbidity (NTU) variability in Oologah Lake, by station, 24 April through
19 September 2001 (letters identify statistically distinct groups).

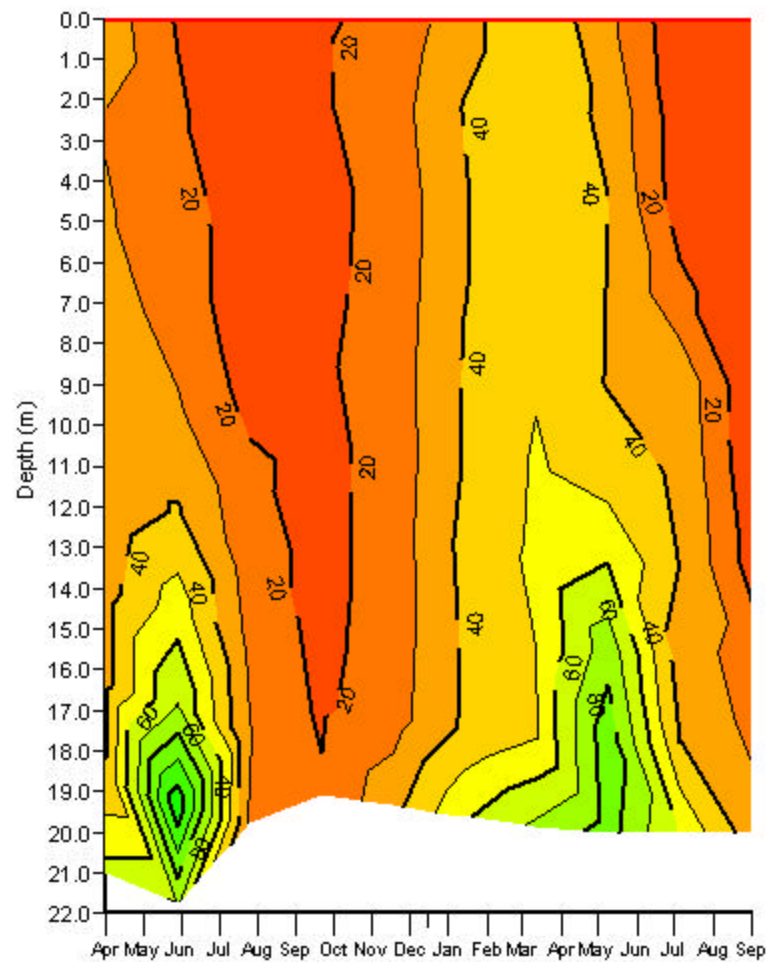


Figure 3.3.2-3
Depth-time diagram of field turbidity (NTU) isopleths at Site 1, Oologah Lake, Oklahoma, 18 April 2000 through 19 September 2001.

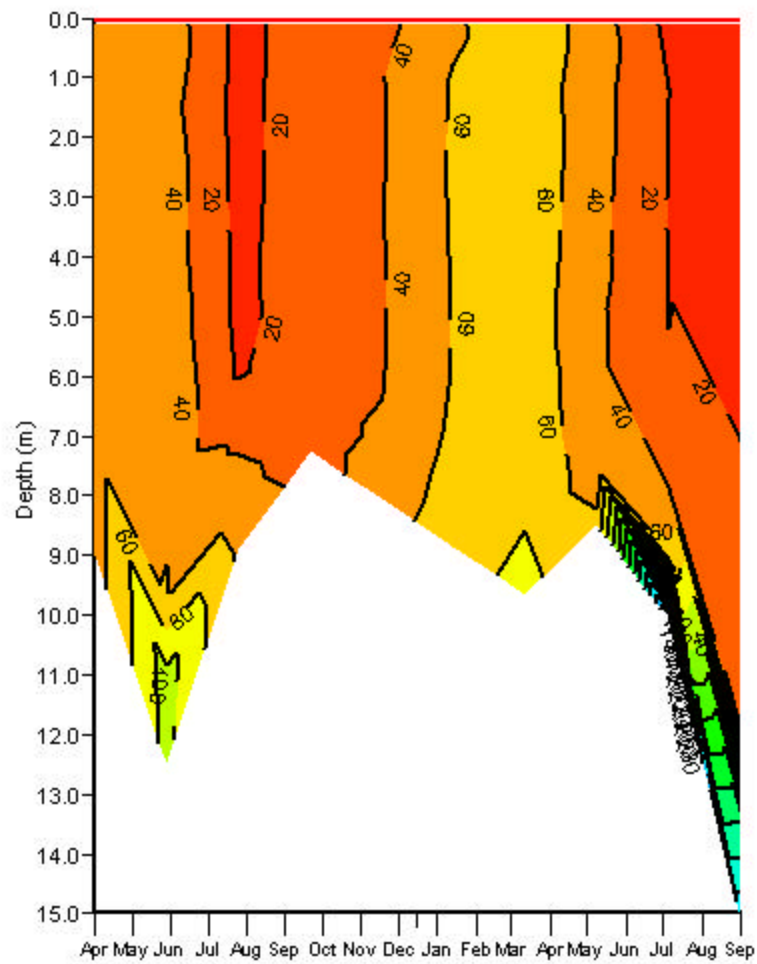
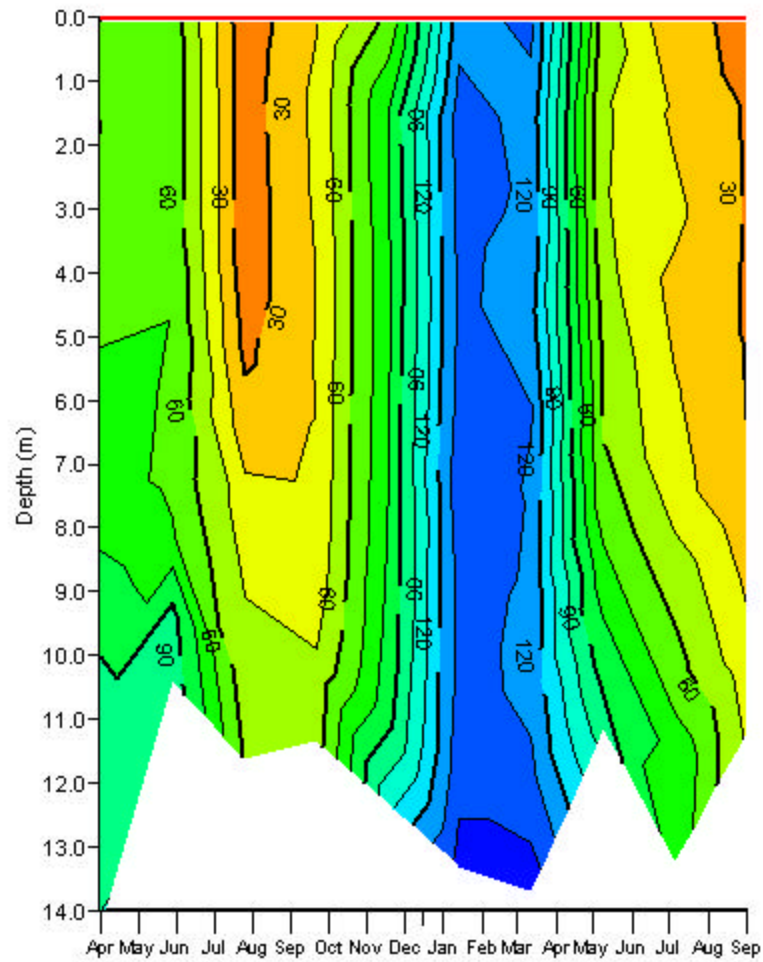


Figure 3.3.2-4
Depth-time diagram of turbidity (NTU) isopleths at Site 2, Oologah Lake, Oklahoma,
18 April 2000 through 19 September 2001.



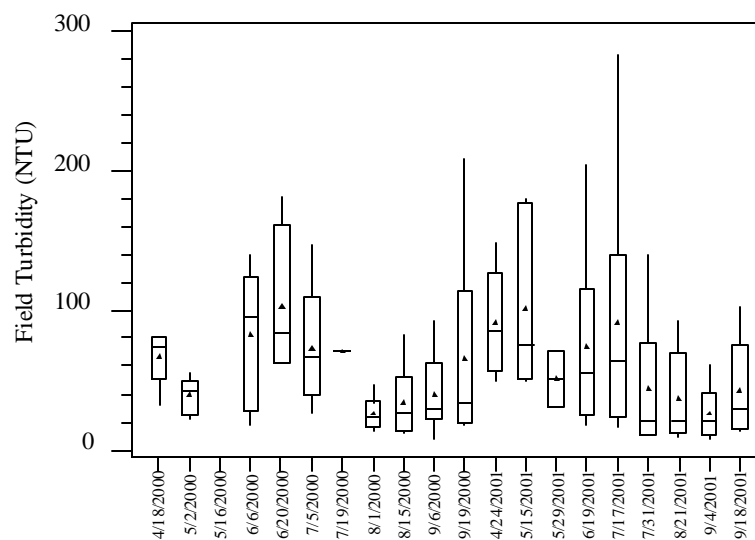


Figure 3.3.2-6
Field turbidity (NTU) variability in Oologah Lake, by date, 18 April through 19 September 2000 and 24 April through 18 September 2001.

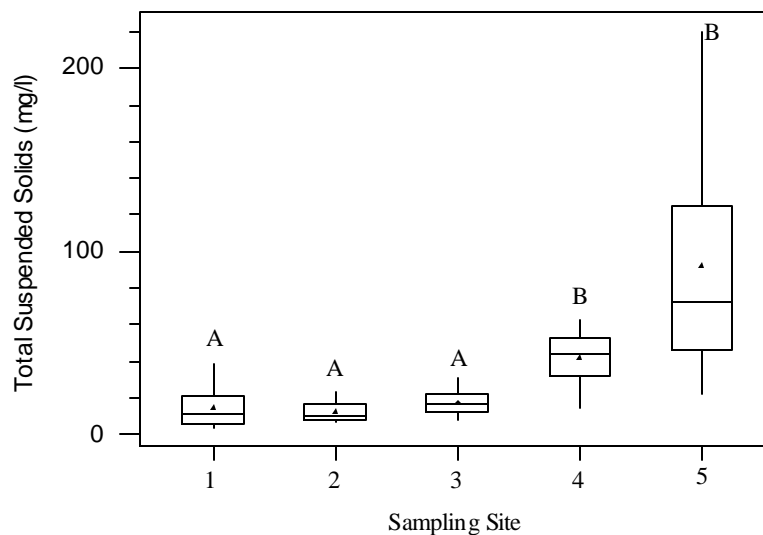


Figure 3.3.2-7
Total suspended solids (mg/l) variability in Oologah Lake, by station, 24 April through 19 September 2001 (letters identify statistically distinct groups).

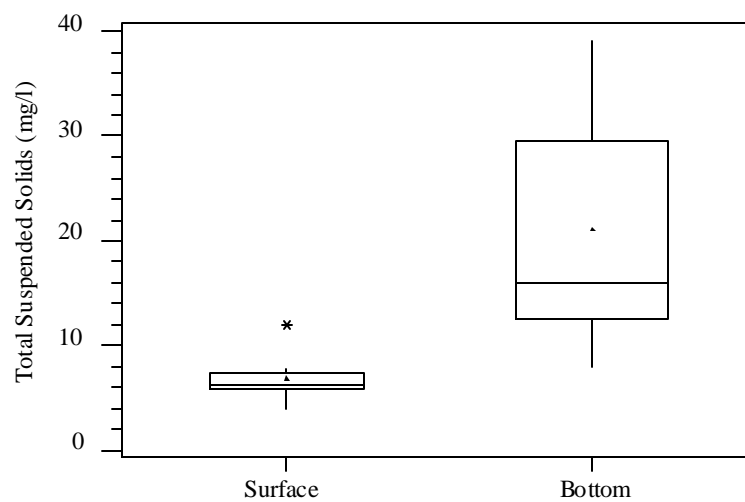


Figure 3.3.2-8
Total suspended solids (mg/l) variability in Oologah Lake at Site 1,
24 April through 19 September 2001.

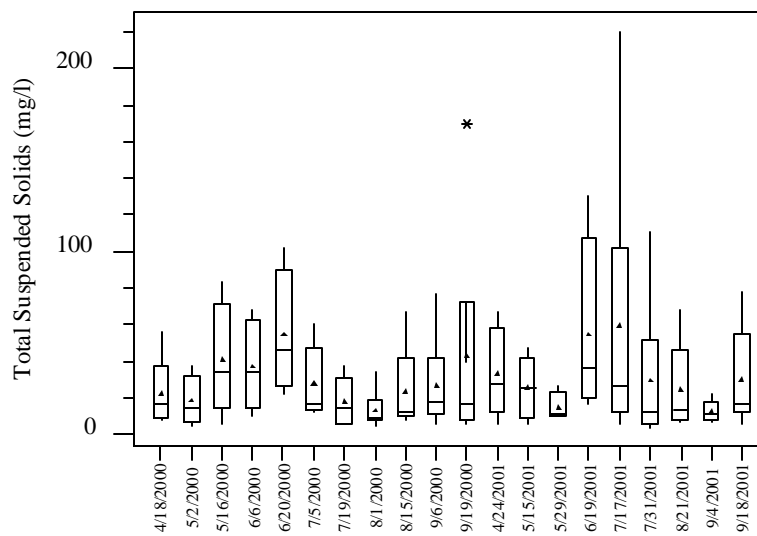


Figure 3.3.2-9
Total suspended solids (mg/l) variability in Oologah Lake, by date,
18 April through 19 September 2000 and 24 April through 18 September 2001.

3.3.3 Metals. Surface samples at each station and samples at depth (Site 1 only) for the total and dissolved metals listed in Table 3.3.1-1 were collected on each sampling event through 19 June 2001. A review of data collected through 19 June 2001 indicated that the majority of metals sampled throughout 2000 and 2001 are, with some exceptions, oftentimes present at or below the practicable quantitation limit. Those metals that were present in measurable quantities a majority of the time included aluminum, calcium, iron, magnesium, manganese, potassium, and sodium.

Table 3.3.3-1 presents the percent difference of dissolved and total aluminum, calcium, magnesium, manganese, potassium, and sodium. With few exceptions, the mean and median concentrations of total and dissolved metals concentrations were higher in 2001 relative to concentrations present in 2000.

Table 3.3.3-1. Percent change in whole lake mean and median concentrations of select dissolved and total metals between 2000 and 2001 in Oologah Lake, Oklahoma (values in parenthesis represent a percent decrease).

Parameter	Mean	Median
Aluminum, Dissolved (mg/l)	31.8	94.1
Aluminum, Total (mg/l)	86.7	77.8
Calcium, Dissolved (mg/l)	9.2	10.2
Calcium, Total (mg/l)	5.1	2.6
Iron, Dissolved (mg/l)	92.9	147.5
Iron, Total (mg/l)	61.1	102.5
Magnesium, Dissolved (mg/l)	1.7	(0.6)
Magnesium, Total (mg/l)	8.2	5.8
Manganese, Dissolved (mg/l)*	84.6	155.0
Manganese, Total (mg/l)	(8.7)	3.2
Potassium, Dissolved (mg/l)	(2.9)	(4.9)
Potassium, Total (mg/l)	(6.3)	3.0
Sodium, Dissolved (mg/l)	7.2	10.0
Sodium, Total (mg/l)	21.4	25.0

* Mean and median dissolved manganese concentrations in 2000 were 0.013 mg/l and 0.009 mg/l, respectively.

Significant differences in median concentrations between study periods were observed for dissolved calcium ($F = 4.71$, $p = 0.036$), total sodium ($F = 21.51$, $p < 0.001$), dissolved sodium ($F = 4.12$, $p = 0.049$), total iron ($F = 10.77$, $p = 0.001$), dissolved sodium

($F = 8.14$, $p = 0.005$), dissolved manganese ($F = 7.51$, $p = 0.010$), and total aluminum ($F = 6.28$, $p = 0.017$). At Site 1, concentrations of total iron and total manganese were significantly greater at the bottom depths relative to surface depths ($F = 6.50$, $p = 0.029$ and $F = 14.54$, $p = 0.007$, respectively). Significant differences between sampling sites were found for dissolved potassium ($F = 4.96$, $p = 0.022$), total potassium ($F = 8.70$, $p = 0.003$), total iron ($F = 10.17$, $p < 0.001$), total manganese ($F = 18.79$, $p < 0.001$), and total aluminum ($F = 11.50$, $p = 0.001$). Each of these parameters exhibited a similar horizontal distribution within the reservoir, with higher concentrations in the riverine portions above Winganon Bridge and decreasing in a down-reservoir direction with the lowest concentrations present nearest the Oologah Dam.

Metal parameters that exhibited a statistically significant temporal trend included dissolved and total magnesium ($F = 2.29$, $p = 0.058$; $F = 4.22$, $p < 0.001$), sodium ($F = 4.37$, $p = 0.002$; $F = 3.87$, $p = 0.005$), potassium ($F = 2.67$, $p = 0.032$; $F = 2.36$, $p = 0.053$), iron ($F = 28.59$, $p < 0.001$; $F = 3.76$, $p < 0.001$), aluminum ($F = 3.68$, $p = 0.007$; $F = 2.08$, $p = 0.083$), and dissolved manganese ($F = 2.13$, $p = 0.060$) when compared across the 2-year study period. There was no single temporal trend common to these parameters, and those trends that were present (Figures 3.3.3-1 through 3.3.3-12) approximate those observed for surrogate parameters, primarily total dissolved solids (Figure 3.3.3-13) and to a lesser degree turbidity (Figure 3.3.2-6).

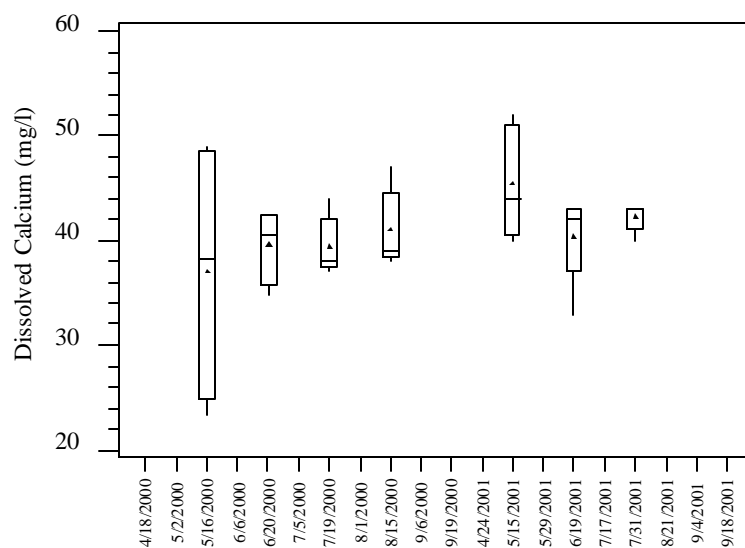


Figure 3.3.3-1
Whole lake dissolved calcium (mg/l) variability in Oologah Lake, by date,
18 April through 19 September 2000 and 24 April through 18 September 2001.

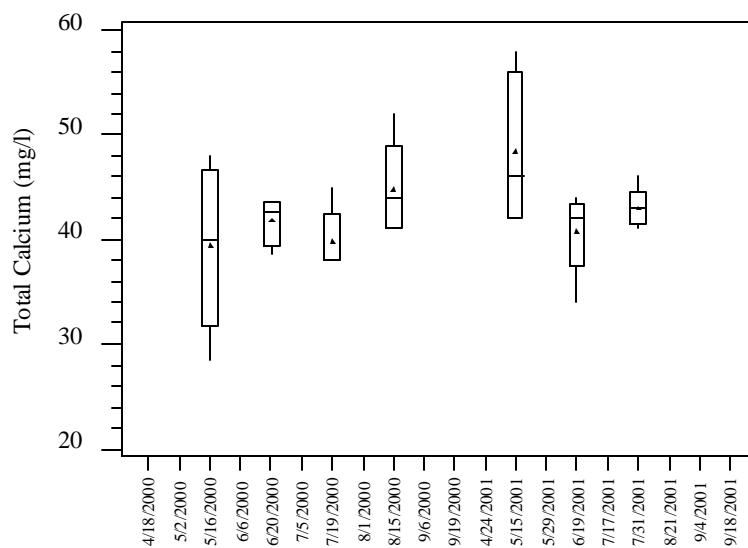


Figure 3.3.3-2
Whole lake total calcium (mg/l) variability in Oologah Lake, by date,
18 April through 19 September 2000 and 24 April through 18 September 2001.

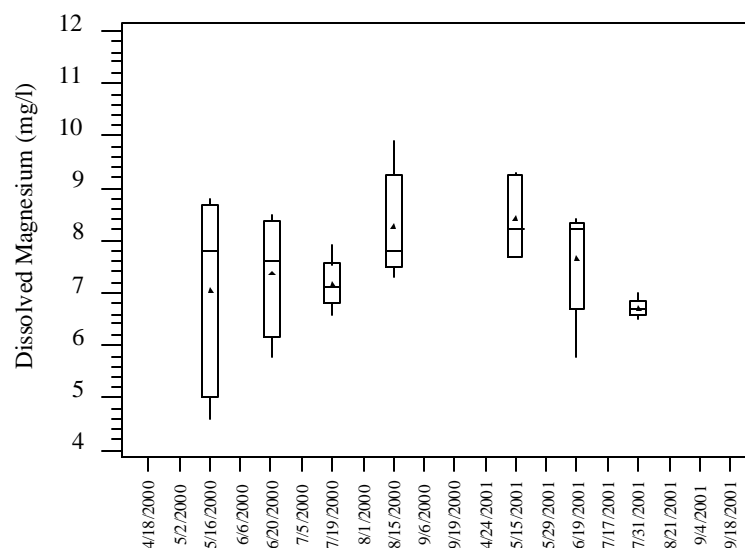


Figure 3.3.3-3
Whole lake dissolved magnesium (mg/l) variability in Oologah Lake, by date,
18 April through 19 September 2000 and 24 April through 18 September 2001.

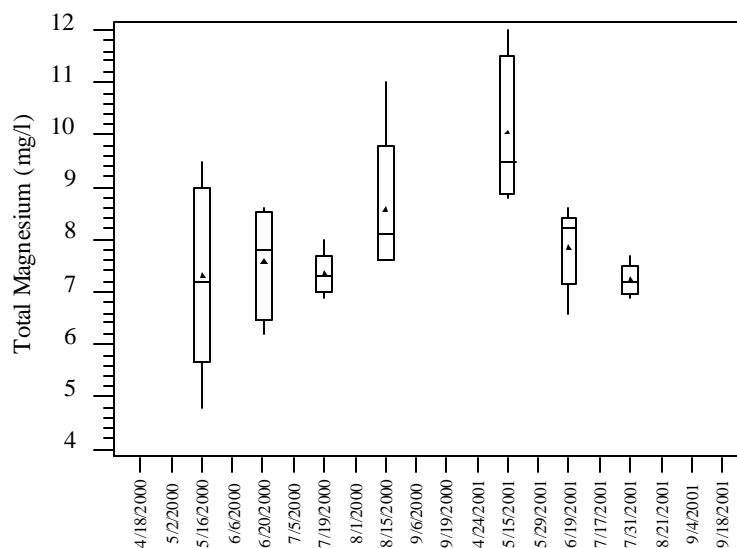


Figure 3.3.3-4
Whole lake total magnesium (mg/l) variability in Oologah Lake, by date,
18 April through 19 September 2000 and 24 April through 18 September 2001.

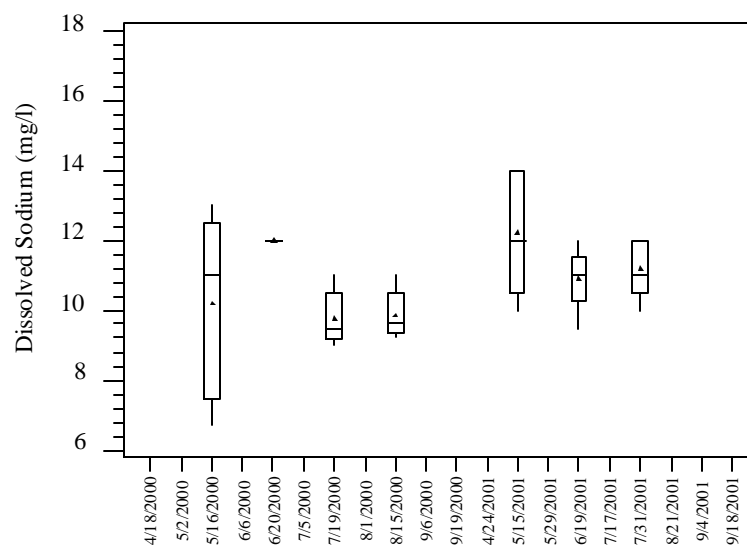


Figure 3.3.3-5
Whole lake dissolved sodium (mg/l) variability in Oologah Lake, by date,
18 April through 19 September 2000 and 24 April through 18 September 2001.

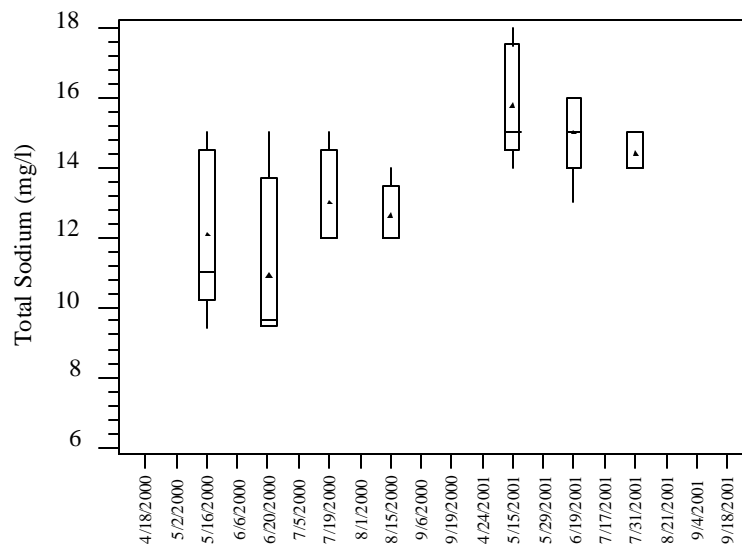


Figure 3.3.3-6
Whole lake total sodium (mg/l) variability in Oologah Lake, by date,
18 April through 19 September 2000 and 24 April through 18 September 2001.

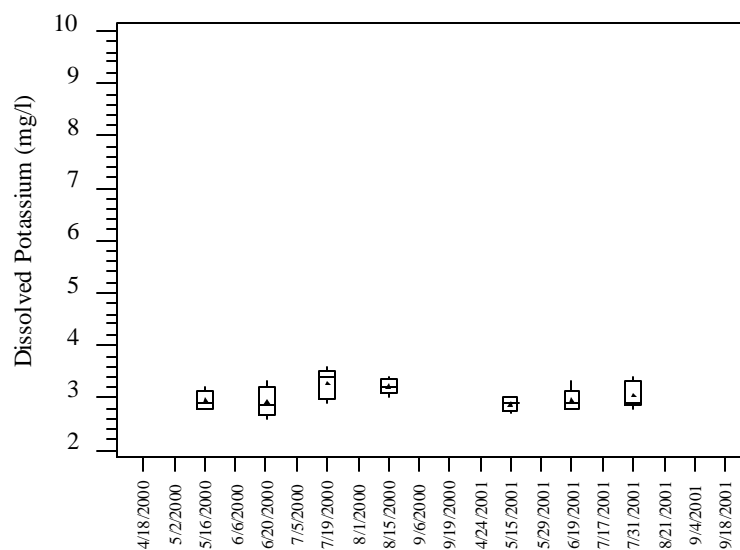


Figure 3.3.3-7
Whole lake dissolved potassium (mg/l) variability in Oologah Lake, by date, 18 April through 19 September 2000 and 24 April through 18 September 2001.

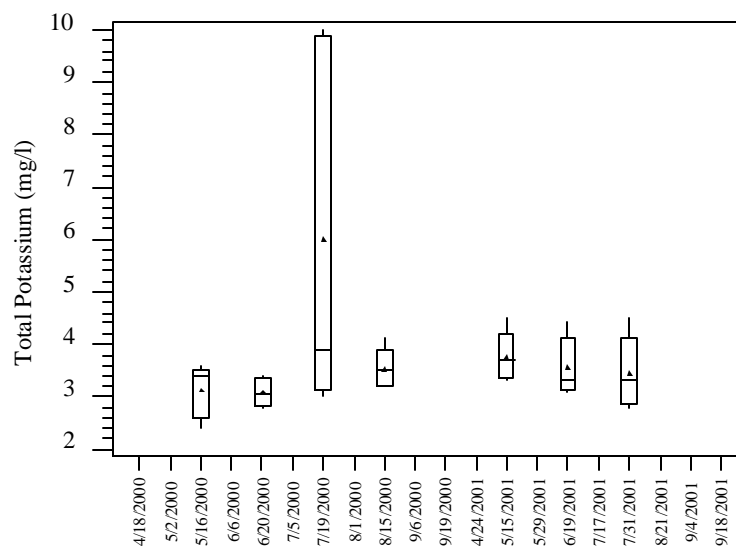


Figure 3.3.3-8
Whole lake total potassium (mg/l) variability in Oologah Lake, by date, 18 April through 19 September 2000 and 24 April through 18 September 2001.

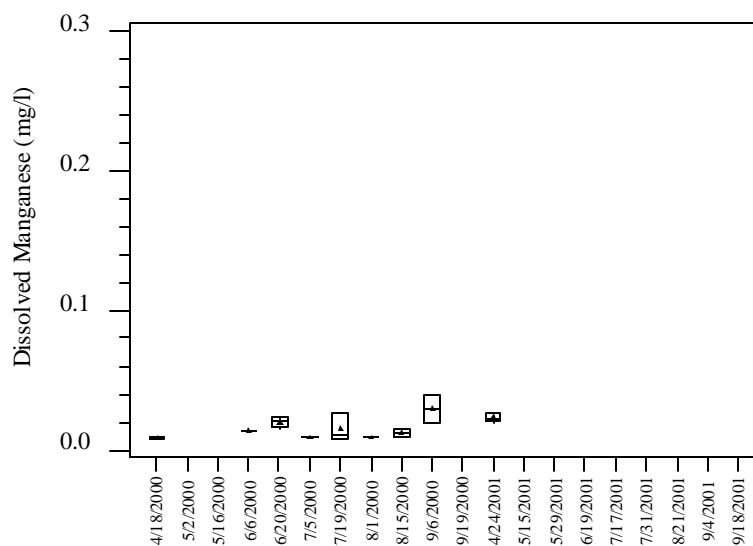


Figure 3.3.3-9
Whole lake dissolved manganese (mg/l) variability in Oologah Lake, by date,
18 April through 19 September 2000 and 24 April through 18 September 2001.

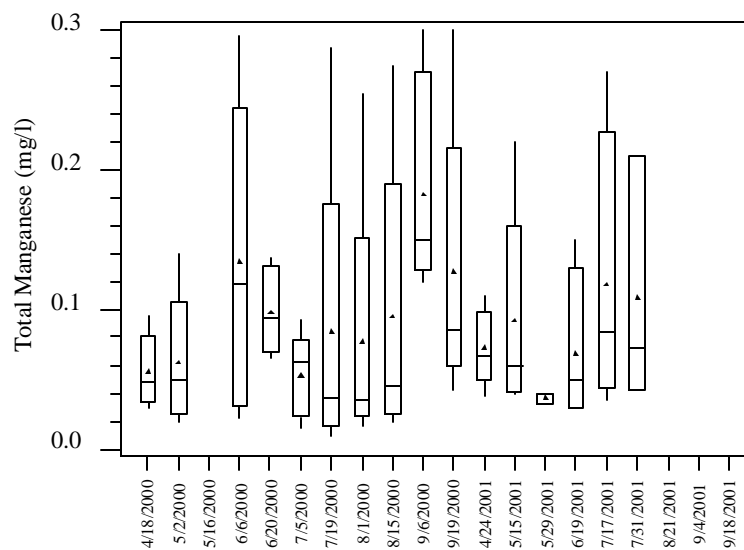


Figure 3.3.3-10
Whole lake total manganese (mg/l) variability in Oologah Lake, by date,
18 April through 19 September 2000 and 24 April through 18 September 2001.

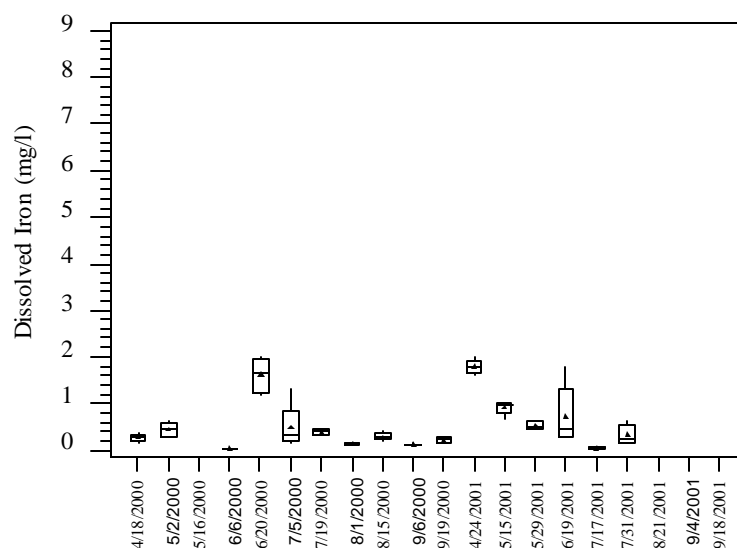


Figure 3.3.3-11
Whole lake dissolved iron (mg/l) variability in Oologah Lake, by date,
18 April through 19 September 2000 and 24 April through 18 September 2001.

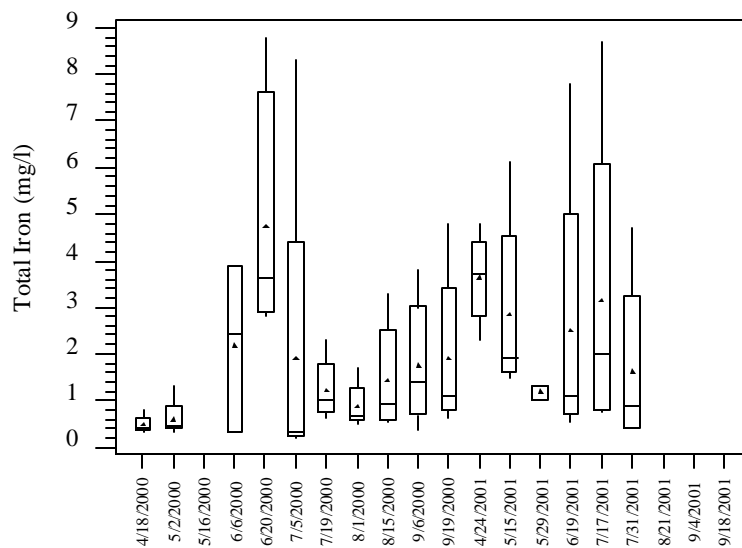


Figure 3.3.3-12
Whole lake total iron (mg/l) variability in Oologah Lake, by date,
18 April through 19 September 2000 and 24 April through 18 September 2001.

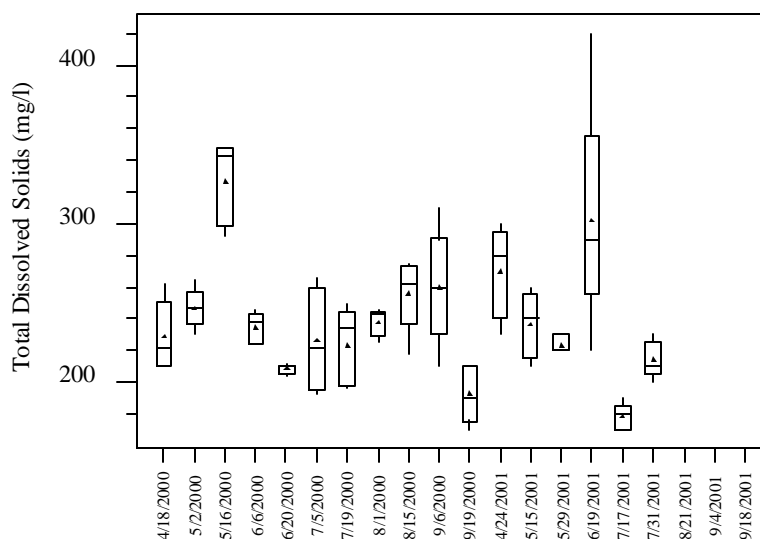


Figure 3.3.3-13
Whole lake total dissolved solids (mg/l) variability in Oologah Lake, by date,
18 April through 19 September 2000 and 24 April through 18 September 2001.

3.3.4 Total Petroleum Hydrocarbons. On four sampling dates toward the end of the study period, water samples were collected, preserved, and analyzed for diesel range organics (DRO) total petroleum hydrocarbons (TPH) using Method SW-846/8015B/3510C. Low level analyses were requested to minimize sample quantitation limits. Samples included primary field samples, quality assurance/quality control (QA/QC) replicates, and field blank samples. With the exception of samples collected at depth (generally 19 m) at Site 1, all field samples were collected at the surface.

Concentrations of DRO-TPH in Oologah Lake water samples are presented in Table 3.3.4-1. Detected concentrations were all very low, at or near quantitation limits, and ranged from 102 µg/l at depth at Site 1 on 23 August 2001 to 494 µg/l in the Site 1 QA replicate sample on the same date. Over this brief sampling interval, petroleum hydrocarbons were detected in 7 of 23 primary field samples for an overall detection frequency of 30%. This was nearly identical to the 31% detection frequency observed during the first year of study at Oologah Lake (USACE 2001), and detected concentrations were likewise similar.

Concentrations of TPH were below sample quantitation limits in all field blank samples and in the single sample (21 August 2001) collected from Oologah Lake tailwaters.

Table 3.3.4-1. Concentrations (ug/l) of diesel range total petroleum hydrocarbons in water, Oologah Lake, Oklahoma. Detected concentrations shown in bold.

	Site 1 (surface)	Site 1 (19 m)	Site 2	Site 3	Site 4	Site 5
21 August 2001	<17.2	<17.2	<17.2 <17.2* <100**	<17.2	<17.2	<17.2
4 September 2001	106	--	<100	<100 <100* <100**	<100	<100
18 September 2001	<17.2	152	<17.2	123	124	155 141* <100**
23 October 2001	<17.2 <17.2** 494*	102	<17.2	136	<17.2	<17.2

* Quality assurance (QA) replicate sample

** Quality control (QC) replicate sample

A statistically significant, negative correlation was observed between lake-wide mean surface water TPH concentration and lake surface elevation during the first year of study at Oologah Lake (USACE 2001). Though sample numbers were limited for 2001 sampling events, TPH detection frequency and average concentration were highest on 18 September 2001 when pool elevation was the lowest (637.56 feet) of the four sampling dates.

3.3.5 Vertical Profiles. As in the 2000 study, vertical profiles of pH (standard units), turbidity, specific conductance ($\mu\text{S}/\text{cm}$), dissolved oxygen (mg/l), and water temperature ($^{\circ}\text{C}$) were recorded at each sampling site on each sampling date from 24 April 2001 through 18 September 2001. Descriptive statistics across all sampling sites, depths, and dates are provided in Table 3.3.1-1.

The vertical behavior of the above listed parameters was similar to that observed in 2000. The only appreciable difference between the two study years, relative to the chemical-physical profiles, was the distinctly different periods of discharge from the reservoir as reflected in pool elevation (Figure 3.3.5-1). The characteristics of stratification observed in 2000 and

described in USACE (2001) are applicable to stratification patterns observed during the 2001 study as well.

The discernable differences in the structure of the vertical profile between the two study periods include overall magnitude in the decrease of water temperature with depth and the length of time hypolimnetic anoxia occurred. It is important to note that the depth-time diagrams on the following pages were generated in a format that does not allow color coding of similar value ranges for the various parameters. Isopleths are labeled with the corresponding value in each of the graphs; however, the color used in each graph might not represent the same range of values from graphic to graphic.

In 2001, the first signs of chemical stratification (i.e., dissolved oxygen concentrations below 2.0 mg/l) were detected on 17 July at Sites 1 and 2 (Figures 3.3.5-2 and 3.3.5-3). For comparison, the first signs of chemical stratification in 2000 were detected on 19 July indicating that hydrology could be secondary to meteorological conditions during the onset of stratification. Unlike the sporadic development of hypolimnetic anoxia observed during summer sampling in 2000, the chemical stratification observed in 2001 was continuous after initial onset at Sites 1 and 2, and hypolimnetic anoxia was observed only once at Site 3 on 8 August 2001. With the one exception of 8 August 2001² at Site 3, Sites 3, 4, and 5 did not experience any chemical or thermal stratification (i.e., metalimnetic temperature change $> 1^{\circ}\text{C}$), and the water column was fairly homogenous with respect to dissolved oxygen (Figures 3.3.5-4 through 3.3.5-6) and water temperature.

While thermal gradients observed in 2001 were not markedly different relative to those observed in 2000, those differences that were observed are noteworthy with respect to the influence of discharge from Oologah Dam on temperature dynamics. While it is apparent from the discussion below that discharge during the period of stratification is important, the influence of wind on the intensity and duration of thermal gradients in the reservoir should not be entirely discounted. As a result of differing hydrologic conditions during the two study years, the overall magnitude of the difference between near surface temperatures (0.1 m) and bottom temperatures (1 m above the bottom) was greater in 2001 following the initial onset of stratification.

The periods with the greatest overall difference between surface and bottom water temperatures occurred throughout July and August (Table 3.3.5-1) and primarily involved Sites 1 and 2 (Figures 3.3.5-7 and 3.3.5-8). Distinct thermal gradients at Sites 3, 4, and 5 were not observed (Figures 3.3.5-9 through Figures 3.3.5-11). Vertical profiles of specific conductance and pH were similar to those observed in 2000, and no deviation from previous studies was observed.

Table 3.3.5-1. Magnitude of temperature decrease (in °C) at chemically stratified sampling sites during the stratification period in Oologah Lake, Oklahoma.

2000			2001		
Date	Station	Magnitude Temperature Decrease	Date	Station	Magnitude Temperature Decrease
19 July	1	3.92	17 July	1	2.74
	2	2.39		2	1.46
	3	2.66	31 July	1	4.54
15 August	1	1.70	8 August	1	6.82*
6 September	1	2.89		2	3.33
				3	4.51
			21 August	1	2.15
			4 September	1	2.18
				2	2.22

* This is the only date where a traditional thermal stratification was observed (temperature > 1 °C per meter).

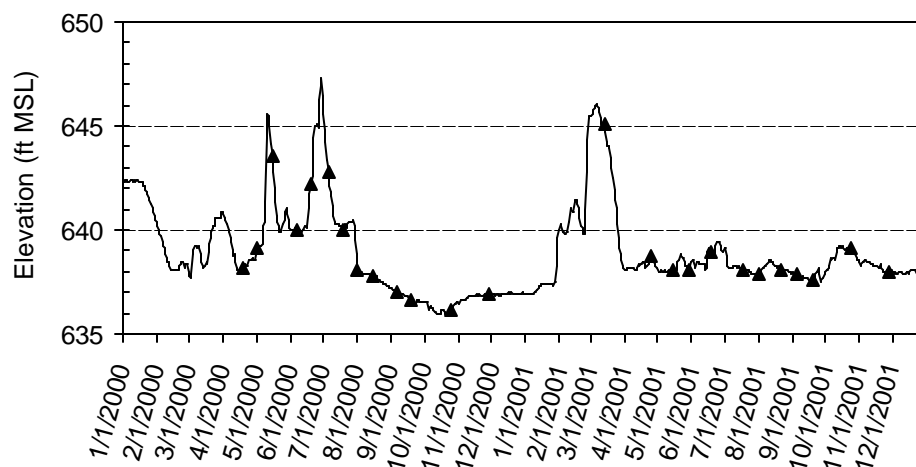


Figure 3.3.5-1
Oologah Lake elevation (feet MSL) from January 2000 through December 2001
(Individual sampling dates indicated by solid triangles).

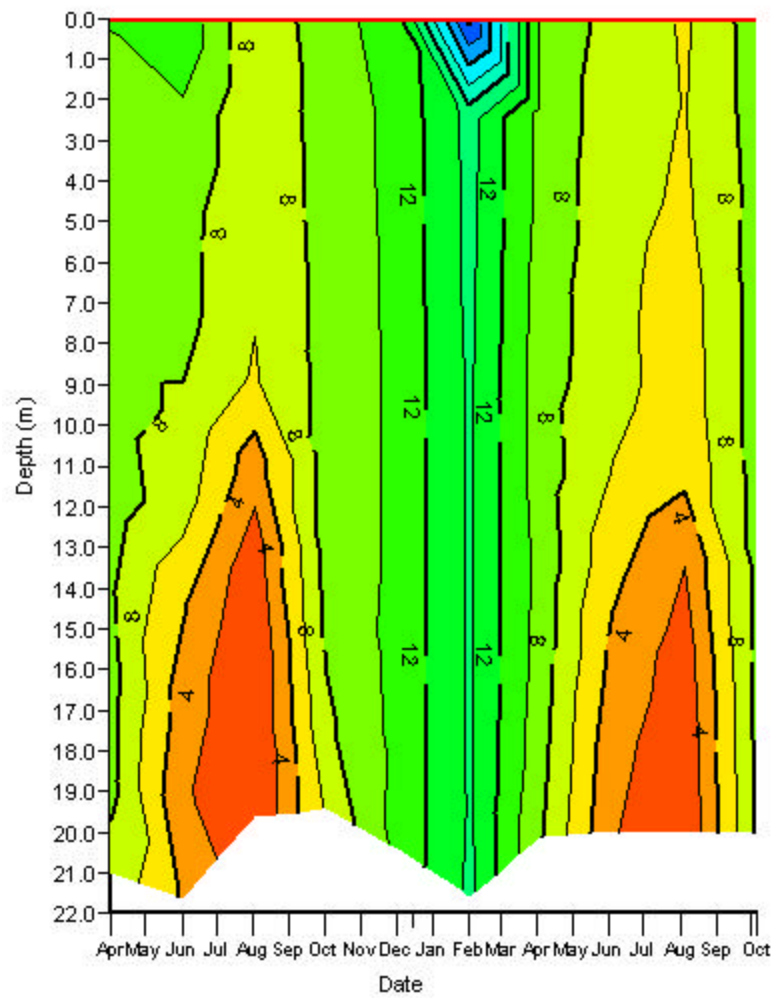


Figure 3.3.5-2
Depth-time diagram of dissolved oxygen (mg/l) isotherms at Site 1,
18 April 2000 through 23 October 2001.

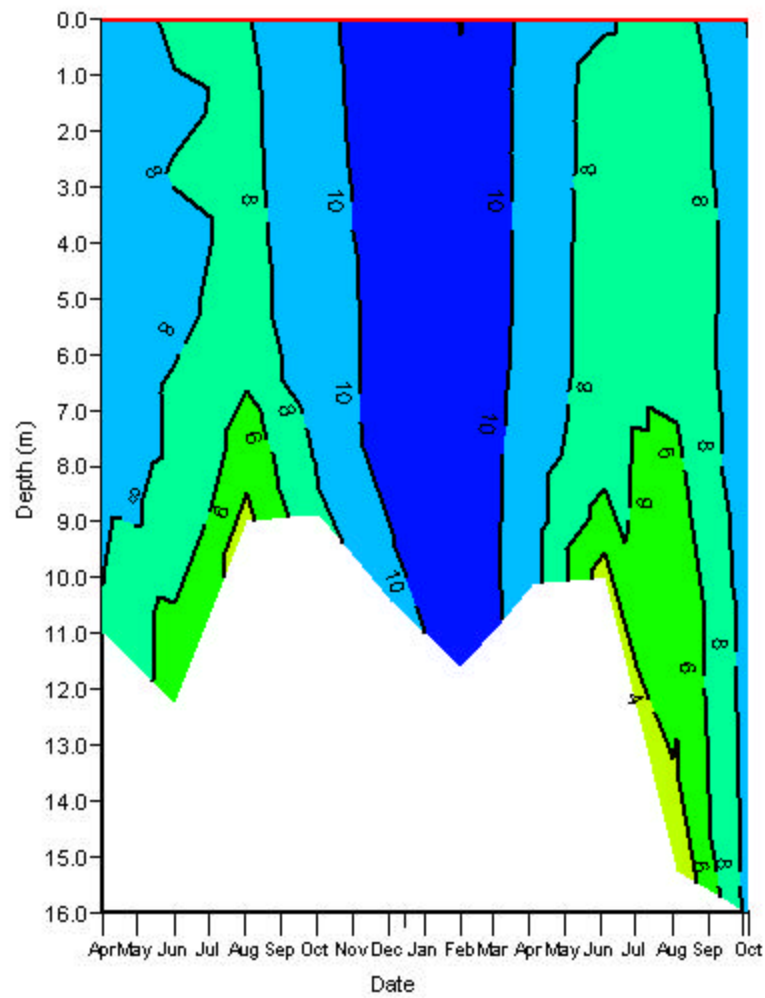


Figure 3.3.5-3
Depth-time diagram of dissolved oxygen (mg/l) isotherms at Site 2,
18 April 2000 through 23 October 2001.

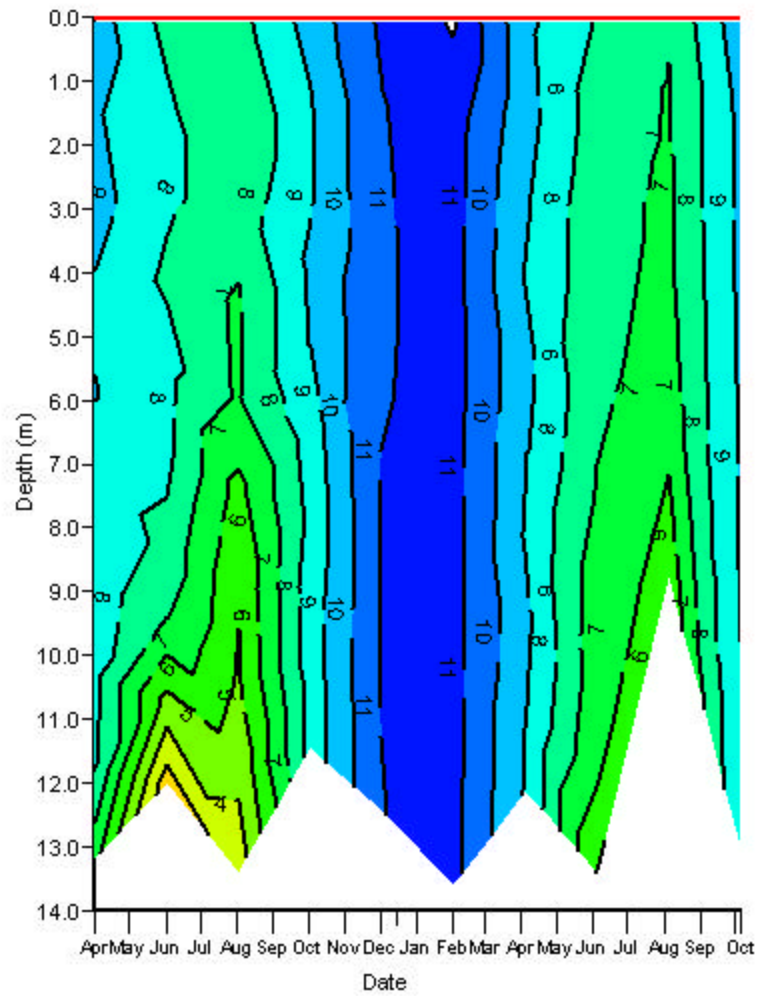


Figure 3.3.5-4
Depth-time diagram of dissolved oxygen (mg/l) isotherms at Site 3,
18 April 2000 through 23 October 2001.

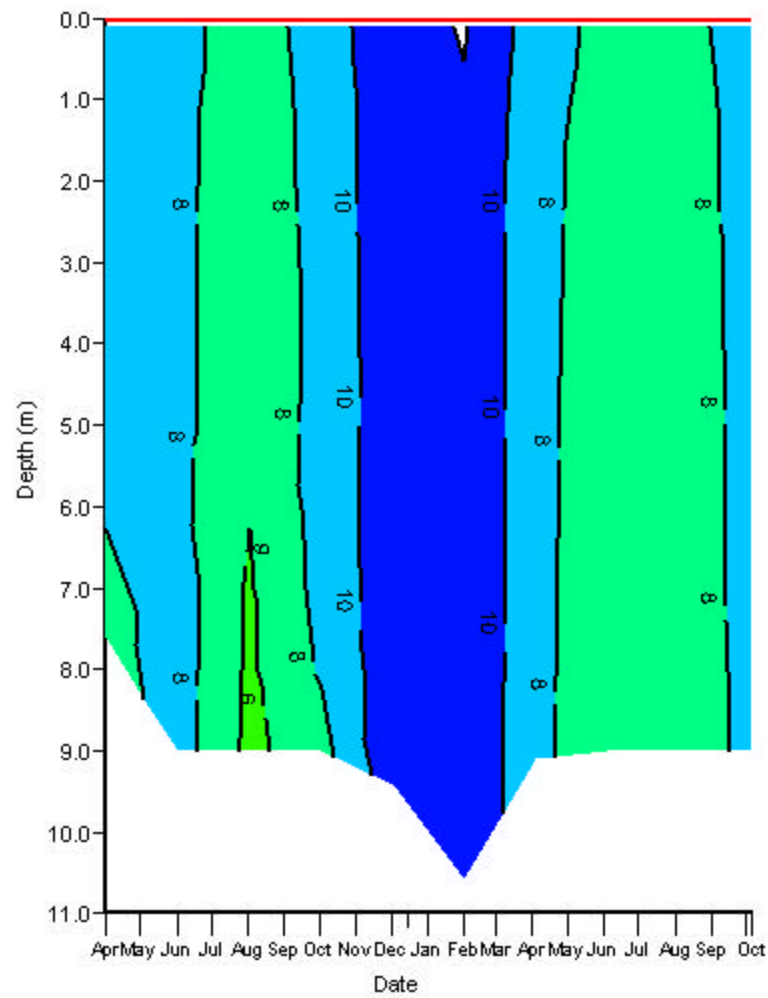


Figure 3.3.5-5
Depth-time diagram of dissolved oxygen (mg/l) isotherms at Site 4,
18 April 2000 through 23 October 2001.

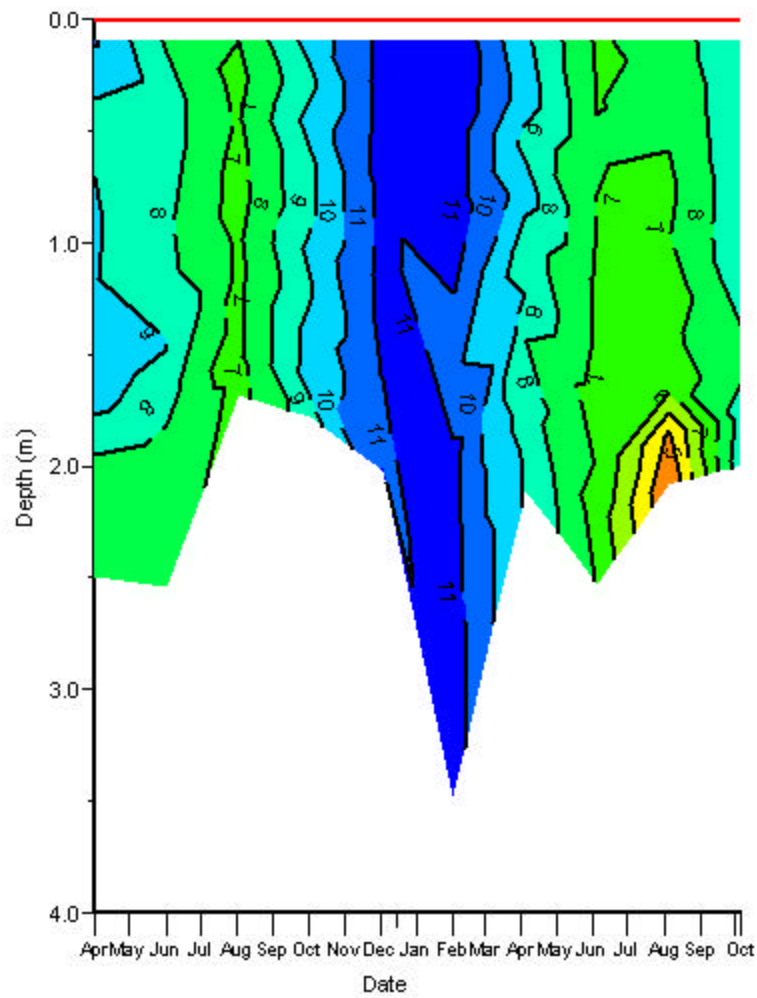


Figure 3.3.5-6
Depth-time diagram of dissolved oxygen (mg/l) isotherms at Site 5,
18 April 2000 through 23 October 2001.

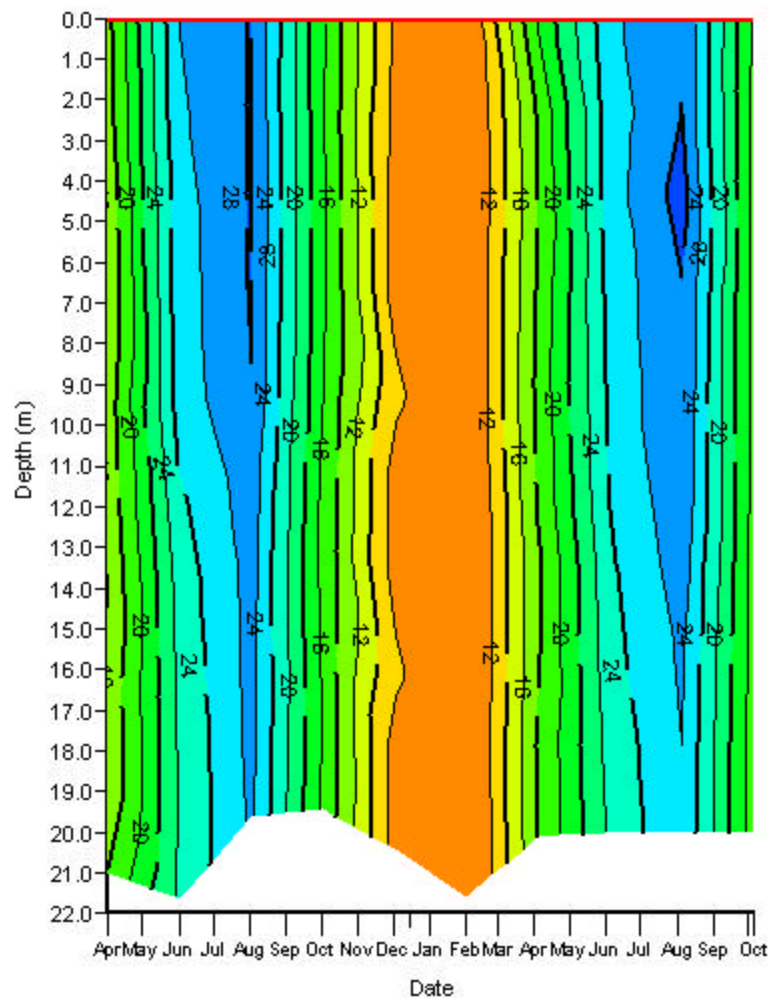


Figure 3.3.5-7
Depth-time diagram of water temperature (°C) isotherms at Site 1,
18 April 2000 through 23 October 2001.

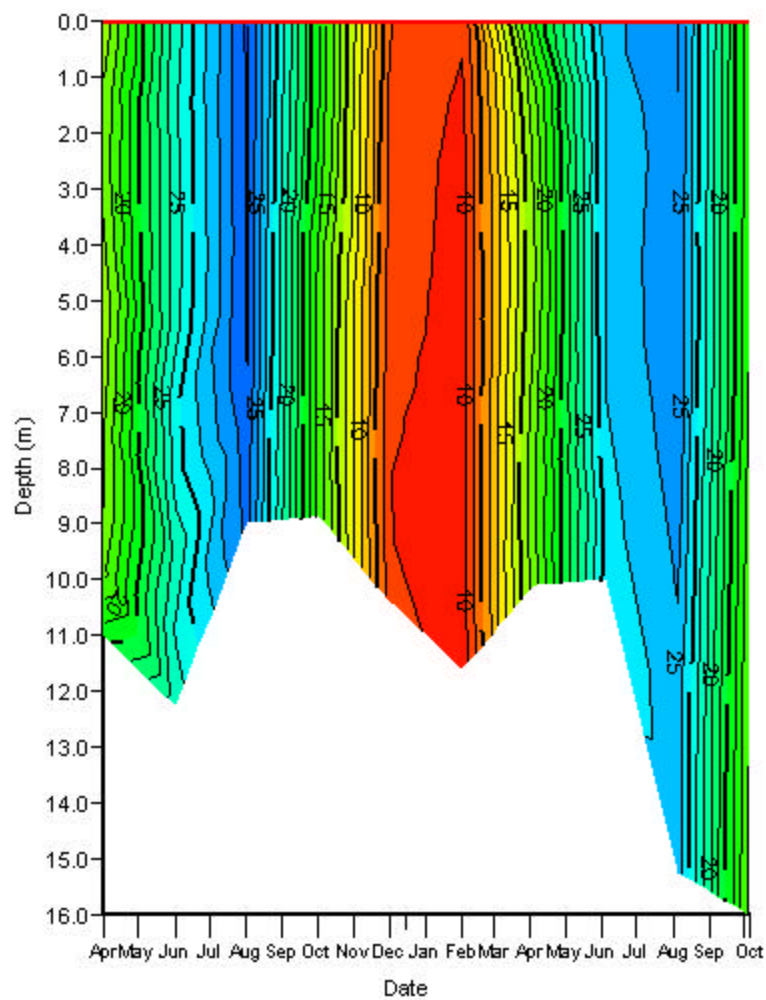


Figure 3.3.5-8
Depth-time diagram of water temperature (°C) isotherms at Site 2,
18 April 2000 through 23 October 2001.

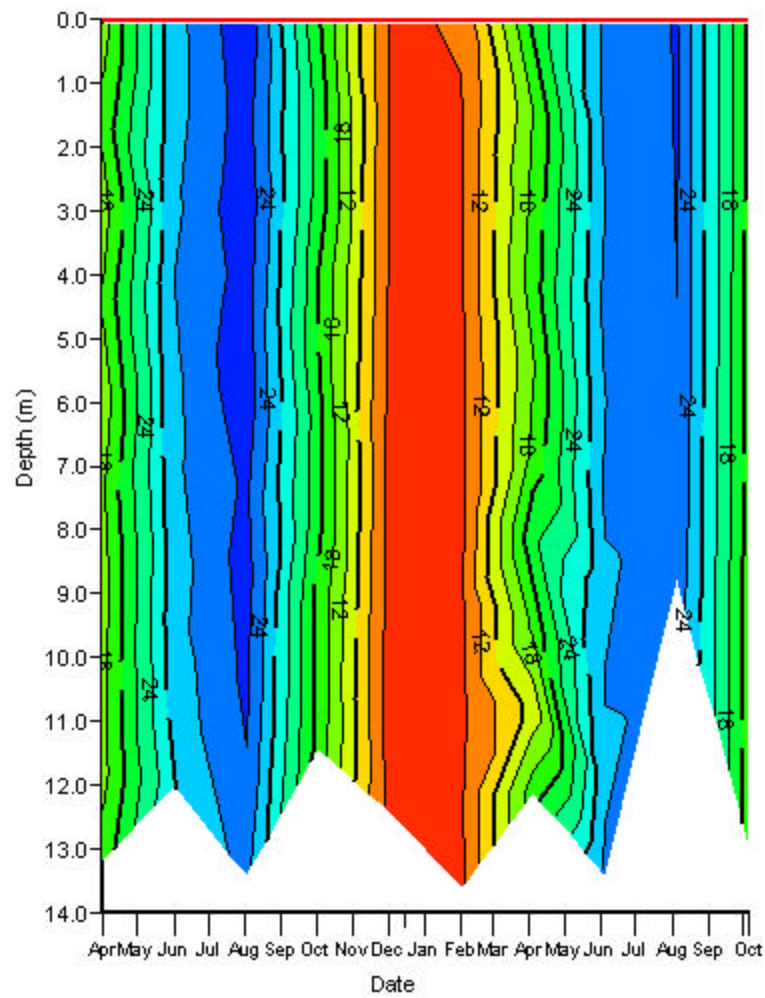


Figure 3.3.5-9
Depth-time diagram of water temperature (°C) isotherms at Site 3,
18 April 2000 through 23 October 2001.

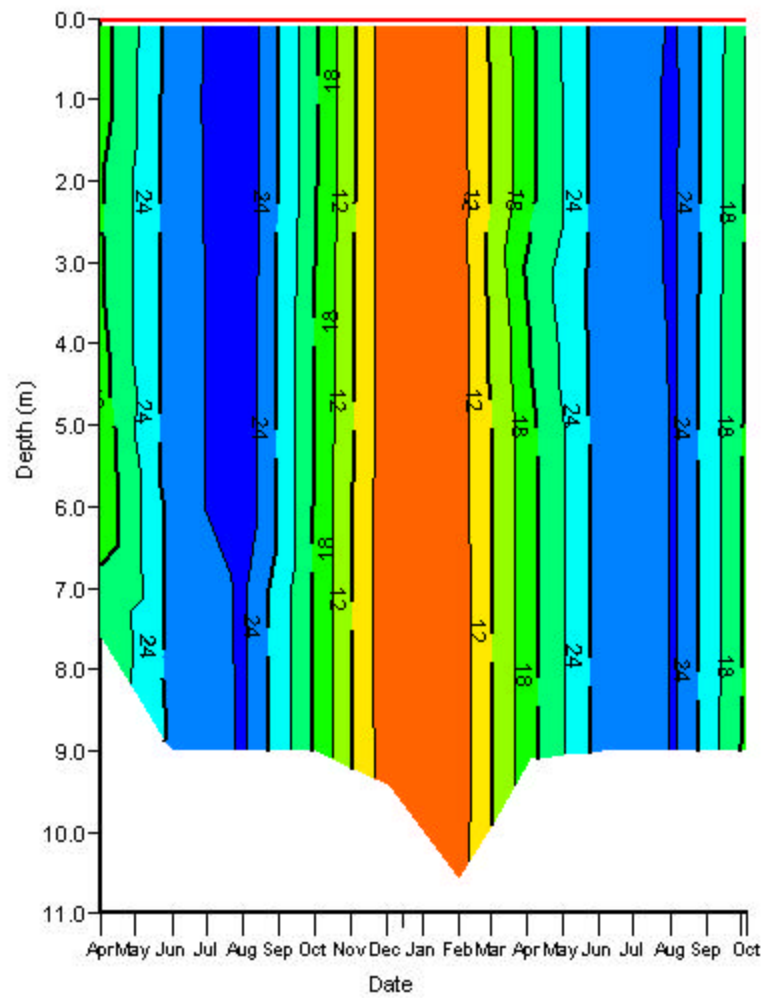


Figure 3.3.5-10
Depth-time diagram of water temperature (°C) isotherms at Site 4,
18 April 2000 through 23 October 2001.

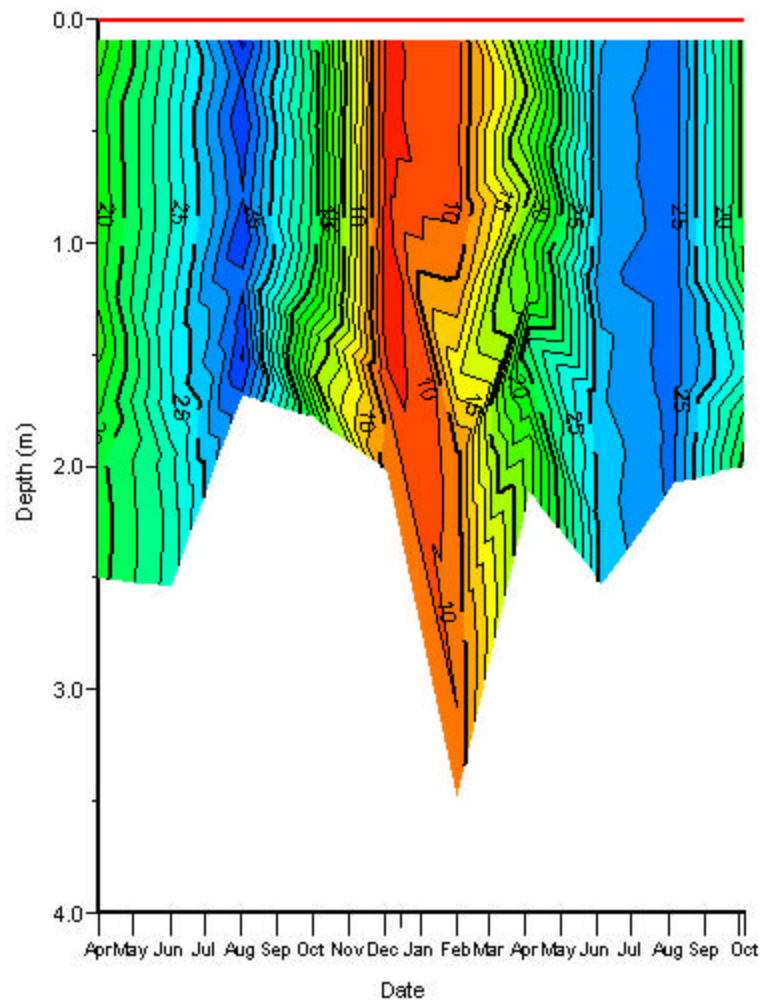


Figure 3.3.5-11
Depth-time diagram of water temperature (°C) isotherms at Site 5,
18 April 2000 through 23 October 2001.

3.3.6 Light and Secchi Data. Light meter and Secchi data collected (April through September 2001) at five in-lake sampling sites in Lake Oologah were again analyzed using the techniques described by Lind (1985) and Horne and Goldman (1994). A LI-COR model LI-192SA was used to record photosynthetically active radiation (PAR) at the surface (0.1 m) and at 0.5-m increments until = 1% of incident surface radiation was detected. Channel 1 of the unit recorded a reference surface reading, and channel 2 simultaneously recorded penetrating radiation at incremental depths. Channel 1 (surface reference) measurements varied due to natural variation, wave action, and cloud cover. Analysis of the data included using the variable surface readings to recalculate interval depth measurements relative to initial surface recordings.

Light attenuation coefficients (k) were calculated for each site by sampling date using the least squares method described by Lind (1985). A k value of 0.69 m^{-1} indicates 50% attenuation per meter, and a value of 2.30 m^{-1} indicates 90% attenuation per meter.

The 2001 results are very similar to 2000, and describe expected conditions in the lake with highest k 's at the upper end of the lake (Site 5) decreasing toward Site 1, the dam site. For the 2001 sampling period, the lowest k was 0.92 m^{-1} measured at Site 1 on 8 August 2001, and the highest was 12.54 m^{-1} measured at Site 5 on 17 July 2001. Light attenuation coefficients were generally increasingly variable moving from Site 1 to Site 5. Site mean k 's were greater than 2.30 m^{-1} (> 90% light attenuation per meter) in the 2001 sampling period for Sites 2, 3, 4, and 5. Mean sampling site light attenuation coefficients were consistently higher in 2001 at all individual sampling sites but not significantly different from 2000 sampling site means. The lake-wide mean k in 2001 was 3.90 m^{-1} , higher than but not statistically different from the 2000 lake-wide mean of 3.47 m^{-1} . A tabular summary of light attenuation coefficients for April through September sampling periods in 2000 and 2001 is presented in Table 3.3.6-1.

Table 3.3.6-1. Light attenuation coefficients (m^{-1}) at Oologah Lake sampling sites for April through September, 2000 and 2001

Year 2000		Site 1	Site 2	Site 3	Site 4	Site 5	Lake-Wide
	Mean	1.90	2.39	2.95	4.15	6.07	3.47
	Median	1.87	2.34	2.67	3.90	6.26	2.55
	Minimum	1.29	1.78	1.66	1.96	2.30	1.29
	Maximum	2.55	3.64	5.28	6.99	11.01	11.01
	St. Dev.	0.39	0.59	1.20	1.68	2.60	2.09
	n	9	8	7	8	8	40
Year 2001							
	Mean	1.98	2.61	3.23	4.59	7.73	3.90
	Median	1.65	2.34	2.58	4.58	7.65	3.20
	Minimum	0.92	1.36	1.90	2.36	2.90	0.92
	Maximum	3.92	3.88	5.16	6.59	12.54	12.54
	St. Dev.	1.16	0.92	1.36	1.41	3.26	2.66
	n	8	6	6	6	6	32
Combined Years 2000 and 2001							
	Mean	1.94	2.48	3.08	4.34	6.78	3.66
	Median	1.75	2.34	2.66	4.22	6.73	2.63
	Minimum	0.92	1.36	1.66	1.96	2.30	0.92
	Maximum	3.92	3.88	5.28	6.99	12.54	12.54
	St. Dev.	0.82	0.73	1.23	1.53	2.91	2.35
	n	17	14	13	14	14	72

Estimation of true euphotic zone depth (Z_{EU}) was determined by inverse prediction of the regression of depth against the natural log of percent light transmission (Atkinson et al., 1999). Average depth of Z_{EU} for the 2001 sampling period was highest at Site 1 (2.99 m) and lowest at Site 5 (0.71 m). The highest calculated Z_{EU} was 4.97 m at Site 1 on 8 August 2001 and the lowest was 0.38 m at Site 5 on 17 July 2001. The lake-wide average depth of Z_{EU} for the lake through the 2001 sampling period was 1.75 m. The 2000 lake-wide average was 1.71 m. Mean sampling site euphotic depths for the 2001 period were lower for all sites except Site 1, but no statistically significant differences were noted. These results are presented in Table 3.3.6-2.

Table 3.3.6-2. Calculated euphotic depth (Z_{EU}) in meters at Oologah Lake sampling sites for April through September, 2000 and 2001

Year 2000		Site 1	Site 2	Site 3	Site 4	Site 5	Lake-Wide
	Mean	2.52	2.01	1.74	1.30	0.90	1.71
	Median	2.48	1.98	1.71	1.19	0.76	1.78
	Minimum	1.81	1.28	0.94	0.70	0.46	0.46
	Maximum	3.56	2.59	2.53	2.32	1.74	3.56
	St. Dev.	0.53	0.43	0.55	0.55	0.40	0.75
	N	9	8	7	8	8	40
Year 2001							
	Mean	2.99	1.91	1.61	1.11	0.71	1.75
	Median	2.80	1.94	1.78	1.00	0.60	1.43
	Minimum	0.53	0.43	0.54	0.49	0.38	0.38
	Maximum	4.97	3.25	2.41	1.92	1.46	4.97
	St. Dev.	1.34	0.79	0.58	0.42	0.39	1.14
	n	8	6	6	6	6	32
Combined Years 2000 and 2001							
	Mean	2.74	1.97	1.68	1.22	0.82	1.73
	Median	2.64	1.96	1.72	1.10	0.70	1.73
	Minimum	1.26	0.96	0.91	0.70	0.38	0.38
	Maximum	4.97	3.25	2.53	2.32	1.74	4.97
	St. Dev.	0.99	0.58	0.54	0.49	0.40	0.94
	n	17	14	13	14	14	72

Table 3.3.6-3 presents descriptive statistics for Secchi depth (SD) measured at each site for sampling periods in 2000 and 2001. Highest mean SD in 2001 was at Site 1 (0.78 m) and lowest at Site 5 (0.17 m). A consistent pattern of decreasing SD from the dam site (Site 1) to the upper part of the lake (Site 5) was again evident across all sampling dates. The maximum observed SD in 2001 was 1.40 m at Site 1, and the minimum was 0.09 m recorded at Site 5. Lake-wide mean SD was not significantly different between the 2001 (0.48 m) and 2000 (0.37 m) sampling periods. No statistically significant differences were found between sampling site mean SDs across the 2000 and 2001 sampling periods.

Table 3.3.6-3. Descriptive statistics for Secchi depth (m) at Oologah Lake sampling sites for April through September, 2000 and 2001

Year 2000		Site 1	Site 2	Site 3	Site 4	Site 5	Lake-Wide
	Mean	0.61	0.44	0.35	0.26	0.21	0.37
	Median	0.58	0.40	0.30	0.22	0.19	0.32
	Minimum	0.31	0.25	0.20	0.12	0.10	0.10
	Maximum	0.90	0.72	0.62	0.55	0.35	0.90
	St. Dev.	0.19	0.16	0.17	0.13	0.09	0.20
	n	11	11	11	11	11	55
Year 2001							
	Mean	0.78	0.66	0.43	0.28	0.17	0.48
	Median	0.76	0.62	0.41	0.26	0.15	0.40
	Minimum	0.35	0.28	0.22	0.15	0.09	0.09
	Maximum	1.40	1.15	0.75	0.42	0.25	1.40
	St. Dev.	0.33	0.29	0.15	0.10	0.06	0.31
	n	10	10	10	8	8	46
Combined Years 2000 and 2001							
	Mean	0.69	0.54	0.39	0.27	0.19	0.42
	Median	0.61	0.41	0.38	0.23	0.15	0.35
	Minimum	0.31	0.25	0.20	0.12	0.09	0.09
	Maximum	1.40	1.15	0.75	0.55	0.35	1.40
	St. Dev.	0.27	0.25	0.16	0.12	0.08	0.26
	n	21	21	21	19	19	101

The product of $h'' \times SD$ was determined for each site on each sampling date, yielding the constant, k , which allows estimation of h'' using only a Secchi disk (Buiteveld, 1995).

Resultant k values are presented in Table 3.3.6-4. Mean sampling site k values were similar among stations in the 2001 study period, ranging from 1.11 at Site 5 to 1.50 at Site 2. The 2000 sampling site mean k values ranged from 1.02 (Site 4) to 1.22 (Site 1). The k values did not show the expected pattern of increasing from zones of high turbidity to zones of low turbidity probably due to the relatively high turbidity throughout the lake.

Table 3.3.6-4. Product (k) of light attenuation coefficient and Secchi depth at Oologah Lake sampling sites for April through September, 2000 and 2001

Year 2000		Site 1	Site 2	Site 3	Site 4	Site 5	Lake-Wide
	Mean	1.22	1.09	1.11	1.02	1.21	1.13
	Median	1.14	1.09	1.03	0.94	1.12	1.07
	Minimum	1.00	0.88	1.00	0.68	0.64	0.64
	Maximum	1.53	1.30	1.35	1.62	1.76	1.76
	St. Dev.	0.19	0.15	0.15	0.31	0.39	0.25
	n	9	8	7	8	8	40
Year 2001	Mean	1.24	1.50	1.22	1.25	1.11	1.26
	Median	1.24	1.45	1.17	1.09	0.93	1.19
	Minimum	1.02	1.09	0.95	0.82	0.73	0.73
	Maximum	1.53	2.12	1.66	2.25	1.88	2.25
	St. Dev.	0.18	0.37	0.27	0.52	0.47	0.37
	n	8	6	6	6	6	32
Combined Years 2000 and 2001	Mean	1.23	1.27	1.16	1.12	1.16	1.19
	Median	1.19	1.18	1.06	0.98	1.10	1.12
	Minimum	1.00	0.88	0.95	0.68	0.64	0.64
	Maximum	1.53	2.12	1.66	2.25	1.88	2.25
	St. Dev.	0.18	0.33	0.21	0.41	0.41	0.32
	n	17	14	13	14	14	72

A constant, derived from the ratio $Z_{EU} : SD$, allows estimation of Z_{EU} in the absence of submarine photometer data (Lind, 1985). Data from each lake site were grouped across sampling dates for this analysis. Resulting $Z_{EU} : SD$ values for the 2001 sampling period ranged from 2.91 (Site 2) to 4.02 (Site 4). Combining data from 2000 and 2001 resulted in a range of $Z_{EU} : SD$ values of 3.64 (Site 2) to 4.52 (Site 4) (Table 3.3.6-5).

Table 3.3.6-5. Mean euphotic depth, mean Secchi depth, and the ratio of Z_{EU} :Mean Secchi depth for Oologah Lake sampling sites for April through September, 2000 and 2001

		Site 1	Site 2	Site 3	Site 4	Site 5
Year 2000	Mean SD	0.61	0.44	0.35	0.26	0.21
	Mean Z_{EU}	2.52	2.01	1.74	1.30	0.90
	Mean Z_{EU} :Mean SD	4.09	4.63	4.91	4.90	4.38
Year 2001	Mean SD	0.78	0.66	0.43	0.28	0.17
	Mean Z_{EU}	2.99	1.91	1.61	1.11	0.71
	Mean Z_{EU} :Mean SD	3.85	2.91	3.79	4.02	4.32
Combined Years 2000 and 2001	Mean SD	0.69	0.54	0.39	0.27	0.19
	Mean Z_{EU}	2.74	1.97	1.68	1.22	0.82
	Mean Z_{EU} :Mean SD	3.96	3.64	4.33	4.52	4.35

3.4 Reservoir Biological Parameters.

3.4.1 Chlorophyll *a*. Surface chlorophyll *a* concentrations by date and site are provided in Table 3.4.1-1. Surface chlorophyll *a* ($\mu\text{g/l}$) concentrations across all sampling sites and sampling dates ranged from 1.2 $\mu\text{g/l}$ to 25.6 $\mu\text{g/l}$, with mean and median concentrations of 7.7 $\mu\text{g/l}$ and 6.9 $\mu\text{g/l}$, respectively. Mean chlorophyll *a* concentrations in 2001 were 16.7% lower and median chlorophyll *a* concentrations were 21.0% greater than mean and median concentrations present in 2000. In general, the interquartile range of chlorophyll *a* values was similar during both study periods, but as shown Figure 3.4.1-1 chlorophyll *a* exhibited a greater degree of variability in 2000 relative to 2001, and median whole lake values were not significantly different between study years.

Table 3.4.1-1. 2001 chlorophyll *a* (mg/l) concentrations for each sampling site on each sampling date. The percent increase or decrease in site mean, relative to the 2000 study, is provided in parenthesis.

Date	Site 1	Site 2	Site 3	Site 4	Site 5	Date Mean
24 April	2.0	1.7	1.9	2.6	6.6	2.9
15 May	3.0	4.6	3.9	5.6	15.5	6.5
29 May	3.3	2.5	3.9	ND	ND	3.2
19 June	1.4	12.5	9.6	8.6	11.2	8.7
17 July	3.0	5.9	7.2	13.7	25.6	11.1
31 July	4.1	7.5	10.1	11.3	14.9	9.6
21 August	4.1	8.2	8.7	3.9	10.5	7.1
4 September	12.3	6.9	4.3	9.5	12.7	9.1
18 September	1.2	6.7	6.9	11.3	22.2	9.7
Site Mean	3.8 (-32.1)	6.3 (16)	6.3 (-11.3)	8.3 (-11.7)	14.9 (-17.7)	

A horizontal gradient in chlorophyll *a* was observed in 2001 with the highest and most variable concentrations being present at Site 5 in the riverine portions of the reservoir (Figure 3.4.1-1). Chlorophyll *a* decreased, both in concentration and variability, in a down-reservoir direction and although median concentrations among stations were significantly different ($F = 7.10$, $p < 0.001$), a good deal of group overlap was found to occur (Figure 3.4.1-1). In addition to surface concentrations of chlorophyll *a*, vertical profiles of chlorophyll *a* were collected on three dates during 2001 in an attempt to better understand phytoplankton distribution and dynamics within the reservoir. The analysis of the vertical chlorophyll *a* profiles presented here is preliminary; a more complete analysis will be incorporated into a separate phytoplankton addendum.

Vertical profiles of chlorophyll *a* are presented graphically in Figures 3.4.1-2 and 3.4.1-3. The trend observed here is very similar to that of vertical chlorophyll *a* distributions observed in Lake Texoma at near dam sampling sites (Gerard A. Clyde, Jr., unpublished data). Of particular interest is the trend of increasing chlorophyll *a* concentration with depth during the summer months to a maximum concentration followed by a gradual decrease in concentration. While this trend was much more dramatic on 8 August relative to 19 June, in both cases this behavior is likely to be an effect of photo-inhibition at near surface depths with light limitation (< 1% incident light), senescence, and/or self-shading responsible for the decrease in chlorophyll *a* concentrations at depths below the euphotic zone. The only release from the reservoir of any magnitude occurred on one date, 19 June. Although discharge has been observed to influence other water quality parameters within the reservoir (e.g., turbidity), discharge does not appear to strongly influence the vertical distribution of chlorophyll *a* given the limited vertical distribution data. The vertical distribution of pheophytin *a*, a degradation pigment of chlorophyll *a* and by-product of senescence, follows expected trends with concentrations increasing with depth. Samples collected on 23 October do not follow trends observed earlier in the year with pheophytin *a* concentrations mirroring concentrations of chlorophyll *a* possibly indicating a period of increased phytoplankton productivity (i.e., an algae bloom) or community equilibrium. However, the data are not sufficient at this time to offer a complete analysis.

Temporally, whole lake chlorophyll *a* concentrations among dates were significantly different ($F = 2.08$, $p = 0.065$), but Tukey's multiple comparison test was unable to differentiate dates. Overall, surface concentrations exhibited a greater degree of seasonality in 2000 relative to 2001. However, given the very different hydrologic conditions experienced over the study periods, the lack of seasonality exhibited by chlorophyll *a* in 2001 is not unusual.

Carlson's Trophic State Index (TSI) (Carlson 1977) was calculated from chlorophyll *a* values for each station and sampling date. Across all sampling sites and dates, the mean TSI (chlorophyll *a*) value was 48.2, which classifies the reservoir, once again, as mesotrophic. Trophic state indices at individual stations resulted in a ranking that ranged from oligotrophic (TSI = 32) to slightly hypereutrophic (TSI = 62). The trophic classification system proposed by

Reckhow and Chapra (1983) resulted in similar trophic rankings (oligotrophic to eutrophic) based upon whole lake chlorophyll *a* concentrations.

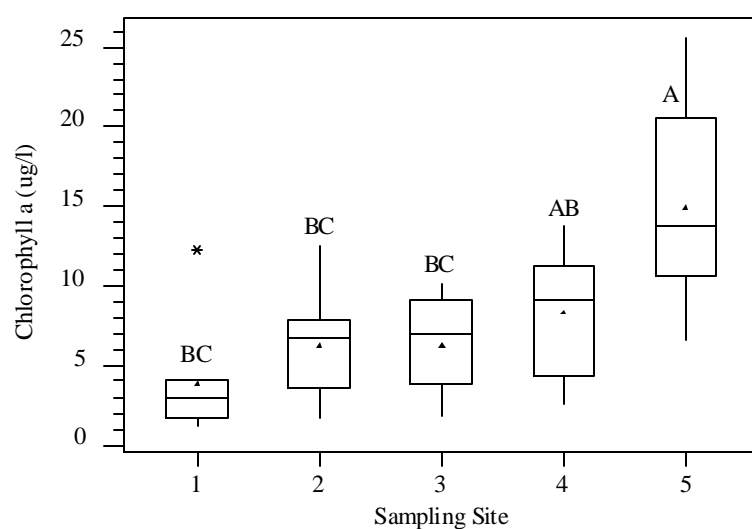


Figure 3.4.1-1
Chlorophyll *a* (mg/l) variability, by sampling site, 24 April through 18 September 2001
(letters identify statistically distinct groups).

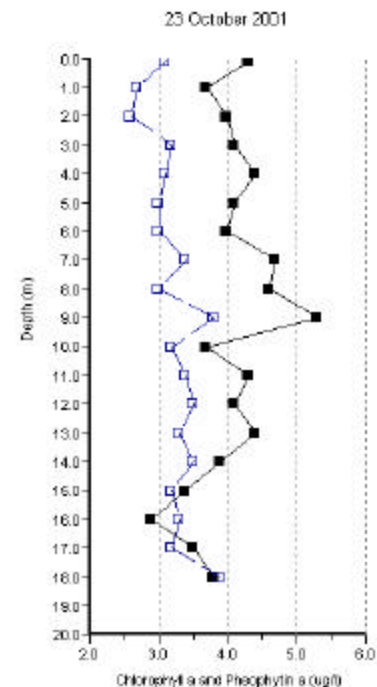
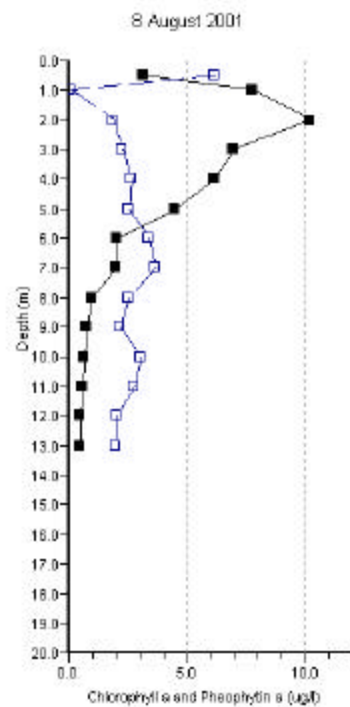
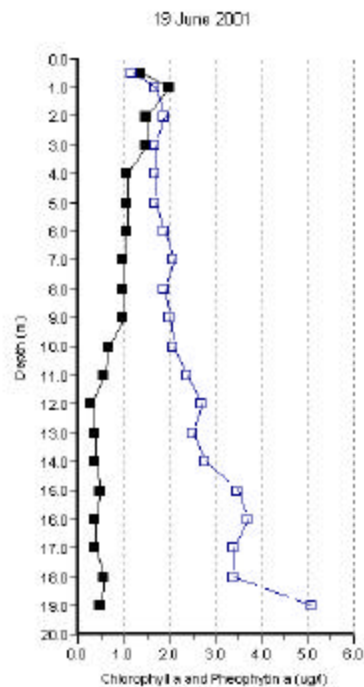


Figure 3.4.1-2
Vertical profile of chlorophyll *a* (closed squares) and pheophytin *a* (open squares)
on 19 June, 8 August, and 23 September 2001 at Site 1, Oologah Lake.

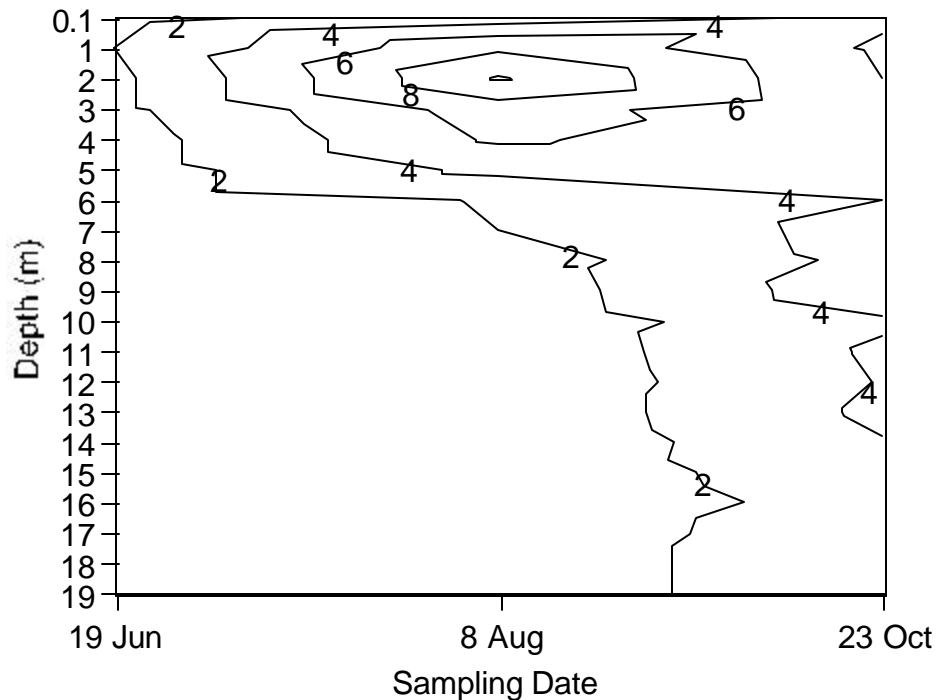


Figure 3.4.1-3
Depth-time diagram of chlorophyll *a* (ug/l) isopleths at Site 1.

3.4.2 Phytoplankton. Phytoplankton samples were collected at a depth of 0.5 m at all Oologah Lake sampling sites (Figure 2.2.1-1) on all sampling dates. Owing to high chlorophyll concentrations in tributary waters, collection of samples for phytoplankton identification and enumeration was likewise initiated for tributary waters during the study period. All samples were preserved and transferred to Dr. Robert A. Lynch of the University of Oklahoma Health Sciences Center for algal analyses. It was the desire of the study team to add estimates of bio-volume and photo documentation to plankton analyses for this project. Accordingly, state-of-the-art analytical equipment capable of providing this information was ordered and has recently been installed. Owing to advantages of obtaining these data, algal analyses were purposely delayed pending installation of this equipment and were not complete at the date of this report. Phytoplankton data will be provided as an addendum to this report once sample analyses are complete.

3.5 Zooplankton. Samples for zooplankton analyses were collected on all sampling dates and preserved to facilitate long-term storage. To date, zooplankton samples (including

those collected during the initial year of study) have been archived for future analyses, funding permitting.

3.6 Sediment Sampling and Analysis. Results of sediment analyses for all samples collected on 8 August 2001 at routine Oologah Lake sampling sites (Figure 2.2.1-1) are presented in Table 3.6-1. Included are data for physical parameters, general inorganics, organic carbon, petroleum hydrocarbons (diesel range), and a number of naturally-occurring metals. Results for each of these general classes of constituents are described separately below.

3.6.1 Physical Parameters. Dry weight solids content in Oologah Lake sediment samples ranged from 27 to 44.3%, with overall mean and median values of 36.5 and 35.1%, respectively (Table 3.6-1). These results were very similar to those reported in samples from the same sites in the summer of 2000 (USACE 2001). Also similar to results obtained in 2000, percent solids gradually increased from Oologah Dam to the upper end of the impoundment.

Particle size distributions in sediment samples collected at Oologah Lake on 8 August 2001 are listed in Table 3.6-1 and depicted in Figure 3.6.1-1. Typically, reservoirs exhibit longitudinal gradients in particle size distribution owing to differential settling of varying sizes of particulate matter in inflowing waters. This particle size sorting generally results in predominance of larger particles (i.e., heavier sands and coarse silts) in sediments of the upper end of an impoundment with a higher proportion of fine-grained materials (i.e., clays) toward the dam (Thornton et al. 1990). This pattern was not clearly evident, and particle size distributions were atypical in limited samples collected in August 2000 at Oologah Lake during the initial year of study (USACE 2001). With the exception of those near Oologah Dam (OOL-1), particle size distributions in samples collected from Oologah Lake in 2001 were more typical of those commonly observed in reservoirs. Though percentage of sands were very low in all samples and particle sizes were dominated by clays at most sites, silt and clay distributions followed rather typical longitudinal distribution patterns from the upper end of the impoundment to OOL-2 (Figure 3.6.1-1). Though sample sizes for both years are limited, this more typical sedimentation pattern in 2001 may reflect the influence of lower inflow conditions on sediment sorting relative to the influence of extreme flow events experienced in 2000.

Table 3.6-1. Results of sediment analyses, 8 August 2001, Oologah Lake, Oklahoma.
Unless otherwise noted, all values are mg/Kg dry weight.

Site (Figure 2.x.x-1)	Aluminum	Antimony	Arsenic	Barium	Beryllium	Cadmium	Calcium	Chromium	Cobalt	Copper	Iron	Lead
OOL-1	38,700	<1	11.20	277	1.92	0.429	8,760	38.8	14.1	29.6	42,200	29.4
OOL-2	22,000	<1	7.91	244	1.49	0.53	6,720	23.4	11.2	24.4	32,500	27.7
OOL-3	23,900	<1	8.88	255	1.54	0.437	6,910	24.9	11.9	23.4	32,000	26.1
OOL-4	28,900	<1	7.56	237	1.51	0.391	5,490	32.8	13.0	23.1	33,300	24.4
OOL-5	16,300	<1	6.96	193	1.22	0.509	7,300	19.0	12.4	20.2	24,800	22.1
OOL-5-QC	20,200	0.864	10.50	196	1.26	0.553	7,010	23.0	12.9	21.3	28,000	21.9
OOL-5-QA	20,700	<9.73	7.39	130	<0.973	<0.973	3,350	23.2	5.25	3.5	13,900	22.6
Mean	25,960	<1	8.50	241	1.54	0.459	7,036	27.8	12.5	24.1	32,960	25.9
Median	23,900	<1	7.91	244	1.51	0.437	6,910	24.9	12.4	23.4	32,500	26.1
Minimum	16,300	<1	6.96	193	1.22	0.391	5,490	19.0	11.2	20.2	24,800	22.1
Maximum	38,700	<1	11.20	277	1.92	0.530	8,760	38.8	14.1	29.6	42,200	29.4
Site (Figure 2.x.x-1)	Magnesium	Manganese	Mercury	Nickel	Potassium	Selenium	Silver	Strontium	Thallium	Vanadium	Zinc	
OOL-1	4,930	1,530	0.038	41.6	5,400	0.953	<0.5	78.1	<1	48.3	135	
OOL-2	3,210	1,130	0.05	29.8	3,000	1.3	<0.5	66.4	<1	32.2	108	
OOL-3	3,570	1,300	0.039	30.5	3,410	<0.5	<0.5	68.9	<1	31.5	107	
OOL-4	4,180	789	0.041	35.2	4,310	<0.5	<0.5	60.9	<1	37.5	114	
OOL-5	3,100	1,080	0.034	26.5	2,270	<0.5	<0.5	61.2	<1	23.4	89.2	
OOL-5-QC	3,450	1,110	0.036	28.5	2,950	0.559	<0.5	60.5	<1	27.5	100	
OOL-5-QA	2,510	471	<0.097	14.4	4,130	0.973	<0.973		<0.973	32.5	59.1	
Mean	3,798	1,166	0.040	32.7	3,678	0.60	<0.5	67.1	<1	34.6	111	
Median	3,570	1,130	0.039	30.5	3,410	0.25	<0.5	66.4	<1	32.2	108	
Minimum	3,100	789	0.034	26.5	2,270	<0.5	<0.5	60.9	<1	23.4	89	
Maximum	4,930	1,530	0.050	41.6	5,400	1.3	<0.5	78.1	<1	48.3	135	
Note: QC and QA samples not included in summary statistics One-half detection limit used for censored data												

Table 3.6-1 (Continued)

Site (Figure 2.x.x-1)	Chloride	Sulfate	Sulfide	Total P	Nitrate-N	Total N	TOC	TPH (DRO)
OOL-1	13	73	<10	348	1.13	-	143	22.7
OOL-2	13.5	83.3	<10	232	1.35	-	186	<0.5
OOL-3	13.2	72.6	<10	382	<1	-	173	13.2
OOL-4	11.5	45.3	<10	475	1.51	-	122	10.4
OOL-5	12.2	14	<10	409	1.3	-	102	18.4
OOL-5-QC	11.7	11.9	<10	331	<1	-	<100	17.4
OOL-5-QA	<10	11.9	12	349	-	500	16,900	<10
Mean	12.7	57.6	<10	369	1.16		145	13.0
Median	13.0	72.6	<10	382	1.30		143	13.2
Minimum	11.5	14.0	<10	232	1.13		102	<0.5
Maximum	13.5	83.3	<10	475	1.51		186	22.7
Site (Figure 2.x.x-1)		%Solids		%Sand	%Silt	%Clay		
OOL-1		27		2.7	50.9	46.3		
OOL-2		31.8		0.3	24.6	75.1		
OOL-3		35.1		0.4	26.2	73.4		
OOL-4		44.1		0.4	30.4	69.2		
OOL-5		44.3		0	43.9	56.1		
OOL-5-QC		43.3		0.5	34.4	65.1		
OOL-5-QA		53		21	18.5	60.5		
Mean		36.5		0.8	35.2	64.0		
Median		35.1		0.4	30.4	69.2		
Minimum		27.0		0.0	24.6	46.3		
Maximum		44.3		2.7	50.9	75.1		
Note: QC and QA samples not included in summary statistics One-half detection limit used for censored data TOC = total organic carbon TPH (DRO) = total petroleum hydrocarbons (diesel range)								

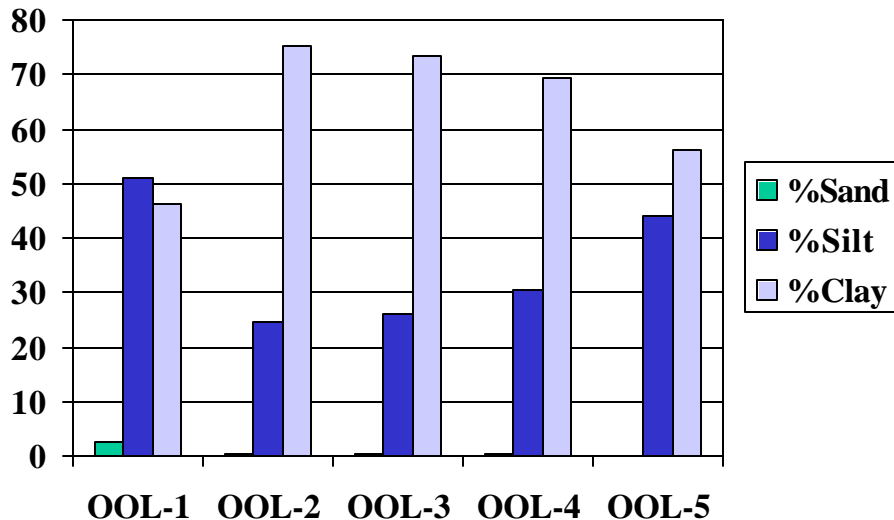


Figure 3.6.1-1
Sediment particle size distribution, 8 August 2001, Oologah Lake, Oklahoma.

3.6.2 General Inorganics. Results of selected inorganic analyses of sediment samples collected from the main pool of Oologah Lake are presented in Table 3.6-1. Sediment chloride concentrations ranged from 11.5 (OOL-4) to 13.5 (OOL-2) mg/Kg, with an overall mean of 12.7 mg/Kg. These concentrations were slightly higher than those measured in 2000 sediment samples (all below the detection limit of 10 mg/Kg). In 2000, sediment sulfate concentrations were all <10 mg/Kg with the exception of a sample from OOL-3 (16.5 mg/Kg) (USACE 2001). Sulfate concentrations for this study were considerably higher. They ranged from 14.0 to 83.3 mg/Kg and generally increased toward Oologah Dam. While measurable concentrations of sediment sulfide were reported in samples from the two down-lake stations (OOL-1 and OOL-2) in 2000, sulfide concentrations in all samples collected in 2001 were less than the quantitation limit of 10 mg/Kg (Table 3.6-1).

Concentrations of total phosphorus (P) measured in Oologah Lake sediments in 2001 are presented in Table 3.6-1 and compared to results from 2000 sediment sampling in Figure 3.6.2-1. In 2001, total P ranged from 232 (OOL-2) to 475 (OOL-4) mg/Kg and exhibited no general longitudinal gradient in the reservoir. Though both mean and median sediment P were considerably higher in samples from 2001 relative to those from 2000 (Figure 3.6.2-1), median concentrations were not statistically different at $\alpha = 0.05$ (Mann-Whitney, $p = 0.0601$).

Sediment nitrate-N concentrations ranged from <1 to 1.51 mg/Kg, with overall mean and median concentrations of 1.16 and 1.30 mg/Kg, respectively (Table 3.6-1).

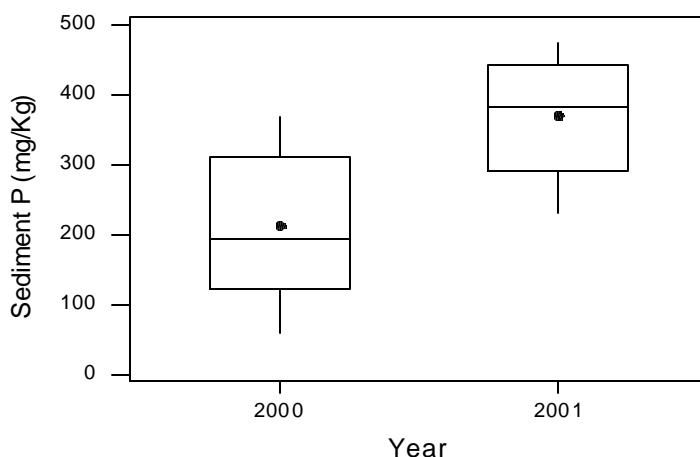


Figure 3.6.2-1
Sediment phosphorus concentrations, Oologah Lake, Oklahoma.

3.6.3 Organic Carbon. Total organic carbon (TOC) concentrations reported for 2001 Oologah Lake sediment samples were extremely low and similar at all sampling sites. Concentrations ranged from 102 to 186 mg/Kg with an overall lake-wide mean of 145 mg/Kg (Table 3.6-1). Sediment TOC concentrations were considerably lower than those measured at the same sites in 2000 (Figure 3.6.3-1), and median concentrations were statistically distinct (Mann-Whitney, $p = 0.0122$). Concentrations from both years were considerably lower and exhibited atypical distributional patterns relative to other Oklahoma reservoirs (see data in Hyne 1978).

Though based on small sample sizes and purely speculative in nature, one possible explanation for significantly reduced sediment TOC in 2001 could involve much lower loading of allochthonous materials (e.g., terrestrial detritus) during the second year of study owing to much lower reservoir inflows during this period. Analysis of C:N ratios in both sediments and tributary inflows was cited as evidence that inputs of allochthonous organics may be relatively

low in Oologah Lake (see discussion in USACE 2001). Lower inflows during the 2001 sampling period may have resulted in even lower organics loading for this period.

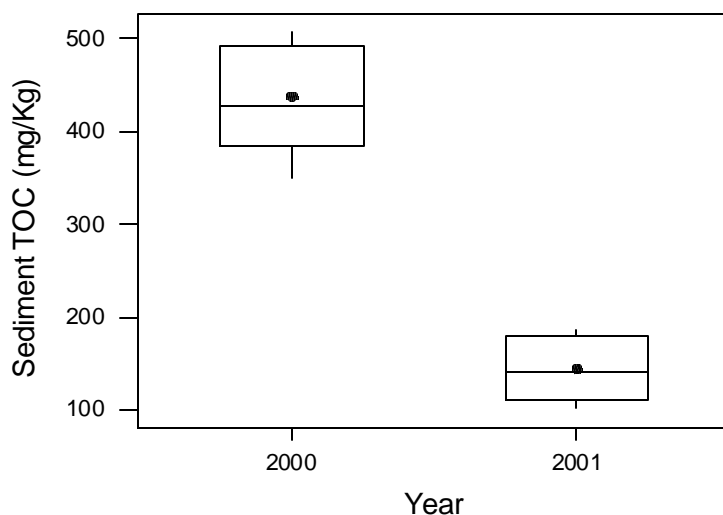


Figure 3.6.3-1
Sediment total organic carbon concentrations, Oologah Lake, Oklahoma.

3.6.4 Petroleum Hydrocarbons. Extractable (diesel range) total petroleum hydrocarbon (TPH) concentrations measured in Oologah Lake sediment samples are presented in Table 3.6-1. Similar to water analyses, detectable concentrations were present in most samples but were low and near the quantitation limit. Concentrations ranged from <0.5 (OOL-2) to 22.7 (OOL-1) mg/Kg, with nearly identical mean and median concentrations of 13.0 and 13.2 mg/Kg, respectively. When compared to results from August 2000 sampling from the main pool of Oologah Lake (Figure 3.6.4-1), concentrations were more variable among sites but median concentrations were not statistically different (Mann-Whitney, $p > 0.99$).

Sediment petroleum hydrocarbon data are limited (or nonexistent) for other Oklahoma reservoirs. It was therefore difficult to determine whether low TPH concentrations measured during both years of study were the result of naturally-occurring petroleum products in the local environment; a reflection of oilfield activities around the lake, residual from boating and similar activities; or a combination of these factors. Regardless, it is apparent that TPH

concentrations are low, at least in areas sampled over 2 years during this study and that significant differences were not apparent between years. Further, these data should prove useful in future petroleum-related monitoring efforts at Oologah Lake.



Figure 3.6.4-1
Sediment total petroleum hydrocarbons, Oologah Lake, Oklahoma.

3.6.5 Metals. Concentrations of 23 metals measured in Oologah Lake sediment samples are presented in Table 3.6-1. These metals are all naturally occurring, but were evaluated as a screen for potential contamination associated with petroleum production or other anthropogenic activities.

Concentrations of all sediment metals in samples for this study period were similar to those measured in Oologah Lake sediments at the same sites in August 2000 (USACE 2001). In fact, hypothesis testing (Mann-Whitney, $\alpha = 0.05$) failed to identify any significant differences in median concentrations for any of the 23 metals except cadmium. The median cadmium concentration for 2001 samples (0.437 mg/Kg) was significantly lower than that for samples collected in 2000 (0.613 mg/Kg) (Mann-Whitney, $p = 0.012$).

In a similar approach to that employed for 2000 sediment data (USACE 2001), both maximum and median values for sediment metals obtained during this study period were evaluated using several criteria. First, metals concentrations were compared to “background” values typical for freshwater sediments as compiled by NOAA (1999). Similarly, concentrations were next compared to soils and other surficial materials metals concentrations in northeastern Oklahoma near the Oologah Lake area as measured by the USGS (1984). Both comparisons are presented in Table 3.6.5-1. While these approaches provide a reasonable general evaluation, caution should be exercised in placing too much emphasis on these comparisons as “background” is difficult to define for an extreme diversity of freshwater environments, and soils and sediments are not directly comparable.

Similar to results from 2000 sediment analyses (US ACE 2001), a number of metals in Oologah Lake sediments collected in 2001 exceeded “background” values typical for freshwater sediments. In addition, a similar subset exceeded northeast Oklahoma surface soil concentrations (Table 3.6.5-1). A probable explanation is close correlation of nearly all metals with the proportion of clay-sized grains (see analysis in USACE 2001) that dominate Oologah Lake sediments, particularly in deeper, main pool areas.

Table 3.6.5-1. Comparison of Oologah Lake sediments metals concentrations with ecological screening criteria.
All values are mg/Kg dry weight. Shaded values exceed one or more screening criteria.

Metal	Oologah Maximum (8/8/2001)	Oologah Median (8/8/2001)	Freshwater Sediment “Background”¹	Northeast Oklahoma Surface Soil Concentrations ²	Threshold Effect Concentration³	Probable Effect Concentration³	Threshold Effect Level¹	Effects Range- Low⁴
Aluminum	38,700 (3.9%)	23,900 (2.4%)	0.26%	0.07-2%				
Antimony	<1.00	<1.00	0.160	<1				
Arsenic	11.2	7.91	1.100	4.1-6.5	9.79	33.0	5.9	8.2
Barium	277	244		10-200				
Beryllium	1.92	1.51		<1				
Cadmium	0.530	0.437	0.100-0.300		0.99	4.98	0.596	1.2
Chromium	38.8	24.9	7-13	50	43.4	111	37.3	
Cobalt	14.1	12.4	10.000	3-10				
Copper	29.6	23.4	10-25	<1-15	31.6	149	35.7	34
Iron	42,200 (4.2%)	32,500 (3.3%)	0.99-1.8%	1.5%				
Lead	29.4	26.1	4-17	<10-10	35.8	128	35.00	47
Manganese	1,530	1,130	400	200-300				
Mercury	0.050	0.039	0.004-0.051	<0.001-0.032	0.18	1.06	0.174	0.15
Nickel	41.6	30.5	9.9	7-15	22.7	48.6	18.00	21
Selenium	1.3	0.25	0.290	<0.1-0.2				
Silver	<0.5	<0.5	<0.500					
Strontium	78.1	66.4	49	<5-100				
Vanadium	48.3	32.2	50	<7-50				
Zinc	135	108	7-38	<5-17	121	459	123.1	150

¹ NOAA (1999)

² USGS (1984)

³ Threshold Effect Concentration (TEC): concentration “below which adverse effects are not expected to occur” (MacDonald et al. 2000)

Probable Effect Concentration (PEC): concentration “above which adverse effects are expected to occur more often than not” (MacDonald et al. 2000)

⁴ Long et al. (1995)

A second means of evaluating Oologah Lake sediment metals data involved comparing maximum reported values with several ecological “screening” values available for selected metals. These values are conservative criteria commonly used to screen chemical constituents in ecological risk assessment. It should be noted that these criteria represent very conservative sediment quality guidelines developed for the most sensitive ecological receptors. Field concentrations exceeding these values do not necessarily indicate definitive impact on ecological receptors, only that further evaluation may be warranted. Values used for these comparisons were “consensus-based” guidelines recently developed by MacDonald et al. (2000), guidelines from Screening Quick Reference Tables developed by NOAA (1999), and those developed by Long et al. (1995). Comparisons are presented in Table 3.6.5-1.

The only metals whose maximum concentrations in Oologah sediment samples exceeded any of the screening criteria were arsenic, chromium, nickel, and zinc (Table 3.6.5-1). For arsenic, the maximum concentration of 11.2 mg/Kg exceeded several screening criteria but was well below the probable effect concentration (PEC) of 33.0 mg/Kg recommended by MacDonald et al. (2000). For chromium, the maximum level (38.8 mg/Kg) barely exceeded the screening level of 37.3 mg/Kg as proposed by NOAA (1999) but was below both the threshold effect concentration (TEC) and the PEC proposed by MacDonald et al. (2000). Both maximum and median concentrations of nickel exceeded several screening criteria but were below the consensus-based PEC (MacDonald et al. 2000). Similar results were observed for zinc (Table 3.6.5-1). Accordingly, while several of these metals may warrant continued investigation in future sampling efforts, none appear to be excessively high or at levels posing significant potential risk to ecological receptors.

3.6.6 Herbicides and Pesticides. Sediment samples from main pool sampling sites at Oologah Lake were analyzed for organochlorine pesticides and chlorinated herbicides. While the manufacture of these compounds has been discontinued, it is possible that they could exist as legacy pollutants in Oologah Lake sediments. However, consistent with results obtained in prior sediment sampling (USACE 2001), no chlorinated pesticides or herbicides were detected in any field, QC, or QA sediment sample collected at Oologah Lake during this study period. Similarly, samples were also analyzed for organophosphorus pesticides with no detection of these

compounds reported for any sample. Finally, owing to detection of very low levels of atrazine in limited water samples collected in 2000 (USACE 2001), this compound was added to the analyte list for sediment samples collected for this study period. Concentrations were below the analytical quantitation limit (167 ug/Kg) in all samples.

3.6.7 Semi-volatile Organics. Sediment samples from all sampling sites were analyzed for semi-volatile organic constituents. Consistent with results from samples collected during 2000, concentrations of all semi-volatile organic compounds were below analytical quantitation limits in all samples collected in 2001 from Oologah Lake.

3.7 Reservoir Modeling. Reservoir modeling using CE-QUAL-W2 was conducted by the Corps of Engineers' Engineering Research and Design Laboratory (ERDC), Vicksburg, Mississippi. Major work efforts included updating the computational grid using newly developed bathymetric mapping (presented in Section 3.1), establishment of time-varying boundary conditions, collection and application of meteorological data as model input, prediction of water surface elevation and comparison with observed data, and reservoir temperature calibration. The report describing modeling efforts conducted as part of this study is provided as Appendix A.

3.8 Watershed Modeling. The Soil and Water Assessment Tool (SWAT), Version 2000 (Neitsch et al., 2001), a basin-scale model, was selected to process digital information to estimate average annual sediment yield and nitrogen and phosphorus loading from the Oologah Lake watershed by generalized land use. SWAT (Arnold et al., 1993) is a basin-scale model "... developed to predict the impact of land management practices on water, sediment, and agricultural chemical yields in large complex watersheds with varying soils, land use and management conditions over long periods of time" (Neitsch et al., 2001). The model is physically based in that it requires specific information about weather, soil properties, topography, vegetation, and land management. SWAT is a continuous time model developed for long-term prediction, estimation, and frequency analysis. The SWAT model is a direct outgrowth of the SWRRB model (Williams et al., 1985; Arnold et al., 1990). Other models that

contributed to the development of SWAT include CREAMS (Knisel, 1980), GLEAMS (Leonard et al., 1987), and EPIC (Williams et al., 1985).

GIS interfaces have been developed for the SWAT model (ArcView and GRASS) to facilitate the aggregation of input data for simulating large-scale basins. The ArcView graphical user interface for SWAT 2000 (AVSWAT2000) (DiLuzio et al., 2001) was selected for use in this application. The ArcView/SWAT interface allows the user to input raster-based map layers for soil information, land use and land cover, and digital elevation information. The SWAT 2000 ArcView extension evolved from an earlier ArcView extension created for an earlier version of the model.

SWAT is a distributed hydrologic model that allows a basin to be divided into smaller subbasins to incorporate spatial detail. In applications of AVSWAT2000, hydrologic response units (HRUs) are created within each defined subbasin. By user direction, the SWAT interface creates HRUs for each land use and soil type combination that occurs within a subbasin. The HRUs do not have direct spatial significance beyond subbasin location and are created for calculation purposes, thus allowing the user to specify model parameters specific to the land use/soil type combinations existing within subbasins. The total export yield for a subbasin is the sum of all HRUs within it. Water, sediment, and nutrient yields from each subbasin are routed through a stream network to the watershed outlet.

3.8.1 Data Inputs. Watershed modeling in the Oologah Lake watershed required spatially referenced digital data describing elevation, land use/cover, soil types and attributes, and weather. Additionally, historical stream discharge from available gaging stations within the watershed, water quality and storage data from upstream ponds and reservoirs, specific crop types and areal extent (by county), livestock types and densities (by county), and commercial fertilizer applications (by county) were collected and used for model calibration and data input to the model. Spatially referenced digital data was reprojected to an Alber's Equal Area projection (spheroid = GRS80, lat1 = 29.5, lat 2 = 45.5, standard meridian = 96W, and standard parallel = 23N).

3.8.2 Elevation. The 107 USGS 1:24,000, 7.5-minute DEM quadrangles in SDTS format (USGS, 1994) completely encompassing the Oologah Lake watershed in both Oklahoma and Kansas were acquired, extracted, processed, and patched together to form a seamless digital elevation model for the entire watershed at 30-meter resolution (Figure 3.8-1). The Oologah Lake watershed boundary and subbasin boundaries were generated from this digital elevation layer using GIS software along with 11-digit HUC boundaries available for Oklahoma (Cederstrand and Rea, 1995) and Kansas Data Access and Support Center (KS DASC, 2001). Additional programs called by the GIS/model interface were used to extract unique runoff, stream, and topographic characteristics for each defined subbasin in the watershed from the digital elevation data.

3.8.3 Land Use/Land Cover. USGS National Land Cover Data (NLCD) (USGS, 2000) developed from recent (1987–1994) Landsat thematic mapper imagery was acquired for both Oklahoma and Kansas at 30-meter resolution. NLCD data from each state had corresponding land cover attributes across State lines and were patched together to create a seamless digital land use/land cover data layer for the Oologah Lake watershed (Figure 3.8-2). Descriptive names and attributes of each land use/land cover were renamed and/or aggregated to match land use categories within the internal SWAT model database, or newly generated for unique land uses. Ancillary data from TIGER files (hydrography, roads, and railways) were obtained for counties encompassing the watershed to enhance the land use/land cover data layer. The Oologah Lake watershed encompasses 1.1 million hectares in Oklahoma (19%) and Kansas (81%). Unmanaged grasslands account for 40% of the total area, managed pasture/hay land accounts for 30%, croplands 11%, forests 8%, and the remainder is distributed between other minor land uses (Table 3.8-1).

3.8.4 Soils. MIADS soils data for Oklahoma counties was obtained from Oklahoma NRCS via Oklahoma State University at 200-meter resolution. Kansas county soils data, obtained through KS DASC (2001), included SSURGO data for 6 of the 12 counties at 30-meter resolution. Digitized county soil survey data for the remaining six Kansas counties were also available at 30-meter resolution. Soils data from each state were patched together to create seamless soils coverage for the Oologah Lake watershed (Figure 3.8-3). Specific soil

types were attributed by SOILS5 IDs, and specific soil characteristics (hydrologic group, bulk density, available water capacity, erosivity, etc.) were retrieved for each soil via a compiled soils database available from the developers of the SWAT model.

3.8.5 Weather. Weather data, including daily precipitation and daily minimum and maximum temperatures, were obtained for all cooperative weather stations across the Oologah Lake watershed for the available period of record through 2001 in both Oklahoma and Kansas (Air Force Combat Climatology Center [AFCCC], 2001). Weather data for each potential station in the watershed was extracted for the longest possible coincident period of record (1955–1999) and formatted for input into the model. Locations of the weather stations are identified in Figure 3.8-4. Details regarding each weather station are presented in Table 3.8-2.

3.8.6 Streams and Stream Discharge. USGS National Hydrography Dataset digital data (USGS, 1999b) identifying stream locations and flow directions were obtained for the Oologah Lake watershed area. The SWAT model incorporated this data along with digital elevation data to determine stream locations, stream connectivity, flow direction, and flow accumulation in the watershed (Figure 3.8-5).

Hydrologic calibration of the model required historical daily mean discharge data from unregulated gaging stations in the watershed. Historical discharge data from all available gaging stations in the watershed were obtained from the USGS (USGS, 1999a). A software program (BFI, Wahl and Wahl, 1996) was used to process downloaded daily mean discharge data to estimate average annual discharge, base flow, and surface runoff components of total discharge at each of the gaging stations for the period of record. These processed data were compared to SWAT simulated hydrologic output to determine the need for model parameter adjustments. Detailed information for USGS gages located in the Oologah Lake watershed are presented in Table 3.8-3.

3.8.7 Subbasin Definition. The Oologah Lake watershed is defined by four 8-digit USGS hydrologic cataloging units (HUCs) including 11070101 (Upper Verdigris, Kansas), 11070102 (Fall, Kansas), 11070103 (Middle Verdigris, Kansas and Oklahoma), and

11070104 (Elk, Kansas). Each of these 8-digit HUCs is further subdivided into 11-digit HUCs that were used as the basis for subbasins modeled within SWAT. Boundaries for the 11-digit HUCs were obtained from Cederstrand and Rea (1995) for the Oklahoma portion of the watershed, and the Kansas DASC (2001) for the portion of the watershed in Kansas. Numbering schemes and boundaries of 11-digit HUCs did not correspond at the State border so that some modification of accounting numbers and boundaries was performed. The final product included thirty 11-digit HUCs that were used as units for reporting sediment and nutrient loading predicted by the SWAT model (Figure 3.8-6). Further subdivision of the 11-digit watersheds was performed using AVSWAT2000 so that output could be generated at USGS gaging stations in the watershed for hydrologic calibration purposes (Table 3.8-4).

3.8.8 Ponds and Reservoirs. Data describing the location, drainage area, surface area, volume, inflows, outflows, and suspended sediment concentrations of reservoirs and ponds are very important for reliable sediment and nutrient export modeling. Data describing major reservoirs in the basin were obtained from the USACE (USACE 1993 and USACE 2001). Pond data were estimated based on water surface area (other than reservoirs) from land use/land cover digital coverages. Table 3.8-5 lists information describing the USACE reservoirs in the Oologah watershed incorporated into the SWAT model.

3.8.9 Crops and Livestock. Information specifying crop types and acreages, livestock inventories, and commercial fertilizer application, by county, provided data important to nutrient loading in this non-point source watershed modeling effort. Recent (1992 and 1997) USDA census data (crop and pasture acreages, animal inventories) were obtained (both years in USDA - NASS, 1997) by county (Table 3.8-6). An animal waste allocation table (Table 3.8-7) was used to calculate an estimated rate of the nutrients nitrogen (N) and phosphorus (P) generated from animal waste applied to crop and managed pasture lands in each county (Table 3.8-8). Rates of animal generated nutrients applied in individual subbasins were estimated using area-weighting methods based on the fraction of each subbasin within a county. Commercial fertilizer (N and P) use estimates for all counties in the watershed were obtained from Alexander and Smith (1990). Rates of commercial fertilizer applications to crop and managed pasture land

uses were calculated by county and were similarly distributed between the crop and pasture land uses within subbasins using area-weighting methods (Table 3.8-9).

3.8.10 Model Calibration. Mean annual total, base, and surface runoff discharge estimates from the SWAT model were adjusted to match, as closely as possible, the estimates made from historical discharge data at selected gaging stations with unregulated flow. A software program (BFI, Wahl and Wahl, 1996) was used to estimate base flow and surface runoff contributions to measured stream discharge at gaging stations with unregulated discharges. SWAT parameters that can be adjusted to calibrate surface flow include the SCS Curve Number II for each land use and a soil evaporation compensation factor. Simulated base flow can be calibrated by altering several SWAT parameters including a groundwater coefficient affecting water movement from the shallow aquifer, the threshold depth of water in shallow aquifer, and groundwater recharge coefficients.

Six USGS gaging stations in the Oologah Lake watershed were determined to be potential sites for hydrologic calibration (USGS 07165700, 07165750, 07167000, 07167500, 07169800, and 07170000). Stream discharge at these sites was unregulated by upstream reservoirs. Adjustments were made to the base SWAT model to match simulated discharge with measured discharge at subbasin outflows corresponding to these gages. The adjustments to the model were designed to first calibrate surface runoff and then base flow, based on comparison to the processed measured mean daily flow data. Results of the calibration at the six unregulated sites are presented in Table 3.8-10. The goal was to get simulated average annual discharge within 10% of measured average annual discharge over the available period of record. Simulated total and surface flows at all six gages were within $\pm 5\%$ of measured flows. Simulated base flow at each of the six gages was within $\pm 10\%$ of the calculated measured base flow. A graphic example of calibration results at USGS 07165700 is presented in Figure 3.8-7.

USGS gages selected for calibration tended to be in the upper portions of 8-digit USGS hydrologic cataloging units (HUCs). Thus, parameters requiring adjustments at these points were also used for other subbasins in the same 8-digit HUC downstream from the calibration station(s). Included in Table 3.8-11 are total discharge comparisons for other gages

in the watershed with flows regulated by upstream reservoirs. Calibration was not performed at these other stations since regulated upstream lake releases do not permit accurate estimation of base and surface components of total flow. Simulated annual mean discharges at these gages were within $\pm 10\%$ measured annual mean discharges for all except USGS 07169500 (-23.5%). Simulated annual mean discharge at USGS 07171000 (Verdigris River at Lenapah), in the lower portion of the watershed, was within 0.9% of measured discharge over the period of comparison (Figure 3.8-8).

3.8.11 Results. The calibrated (hydrologic only) SWAT model of the Oologah Lake watershed was run for a 45-year period based on the coincident period of record (1955 – 1999) of the available weather stations. The model simulated currently available land use determinations throughout the period. Reservoirs were modeled only as hydrologic components with sediment trapping functions, and the operational dates (month and year) of each reservoir were used as the beginning of reservoir functionality through the simulated period. Basin areas occupied by water (ponds and reservoirs) were not modeled as a land use, but were included in hydrologic, sediment, and nutrient export calculations.

Hydrologic response units (HRUs), land use and soil combinations within each subbasin serve as basic functional units of the model. HRUs were defined as land uses accounting for at least 1% of subbasin area combined with soils accounting for at least 10% of the subbasin area. This resulted in 1,013 HRUs for the entire watershed, or an average of ~24 HRUs for each of the 42 subbasins that were defined in the SWAT model. Model output data was aggregated to reflect results for the thirty 11-digit HUC watersheds in the Oologah Lake watershed.

Modeled land management scenarios were simplistic. Croplands were fertilized, harvested, and tilled on an annual basis. Managed pasture land was fertilized on an annual basis. Roads in the watershed, obtained from TIGER files, were all modeled with an impervious (hard surface) soil. Digital information identifying attributes of roads (hard surface, gravel, soil, stone) were not available. Information from the Kansas Department of Transportation (1994) indicates

that of the 136,225 miles of roads in the State of Kansas, ~55% have soil, gravel, or rock surfaces. Road with soil and gravel surfaces may contribute significantly to sediment export.

Since calibration of sediment and nutrient export in the SWAT model of the Oologah Lake watershed has not yet been performed, reported values for these parameters should be viewed in relative, rather than absolute, terms. Results identify the relative magnitude of subbasin and land use contributions to sediment yield and nutrient export.

Simulated average annual basin-wide precipitation was 985.6 mm (38.8 in.) over the 45-year period, with 229.6 mm/yr (9.04 in./yr) surface runoff. Highest average annual runoff was predicted for subbasin 11070103050 (344 mm/yr) and lowest for subbasin 11070102010 (179 mm/yr). Runoff carried an estimated annual average 5.16 metric tons (t) of sediment per hectare per year, 4.80 kg/ha/yr organic nitrogen (as N), 1.26 kg/ha/yr nitrate (as N), 0.37 kg/ha/yr soluble phosphorus (as P), and 0.49 kg/ha/yr sediment-bound phosphorus (as P).

Tabular summaries of simulated average annual export of sediment, organic nitrogen, nitrate, soluble phosphorus, and sediment-bound phosphorus by 11-digit HUC subbasin are presented in Table 3.8-12. Basin maps indicating locations of subbasins and relative rates of average annual runoff, sediment export, and nutrient yields are included in Figure 3.8-9 through Figure 3.8-16. Graphics describing predicted annual average runoff, along with sediment and nutrient export, by subbasin, are included in Figure 3.8-17 through Figure 3.8-21.

Highest predicted annual average sediment yield was 16.42 metric tons (t)/ha in subbasin 11070101090. The lowest estimated average annual sediment yield was in subbasin 11070103051 (0.31 t/ha). Organic nitrogen export rates were highest for subbasins 11070101090 (8.89 kg/ha) and 11070101110 (10.27 kg/ha), and lowest in subbasins 11070103031 (1.82 kg/ha) and 11070103051 (1.26 kg/ha). Nitrate export ranged from 0.73 kg/ha (11070102010) to 3.80 kg/ha (11070103050). Phosphorus export estimates were also highest in subbasin 11070103050 (1.07 kg/ha soluble phosphorus and 0.95 kg/ha sediment-bound phosphorus) and lowest in subbasin 11070102010 (0.15 kg/ha soluble phosphorus and 0.23 kg/ha sediment-bound phosphorus).

Table 3.8-13 lists the same sediment and nutrient export information for each subbasin broken down by contribution from the various land uses. Subbasins with a higher percentage of agricultural land uses (row crops) tend to have higher average annual sediment export rates. The subbasin with highest estimated annual average sediment export rate (11070101090) has 19.4% of subbasin area identified as row crop. The subbasin with the lowest average annual sediment export rate (11070103051) did not have any land modeled as row crop. A similar pattern exists for nutrient export in the Oologah Lake basin. Subbasins with a greater percentage of land area designated as crop (row and close grown) tend to have higher average annual export rates.

Estimated basin-wide annual average export rates of sediment and nutrients by land use are presented in Table 3.8-14. Predicted average annual sediment loading rates are highest for cropland (47.49 t/ha for row crop and 6.43 t/ha for close grown crop) and lowest for forests (average of 0.10 t/ha). Land uses accounting for the greatest percentage of total basin area, range (41.8%) and pasture (31.1%), have average annual export rates of 0.41 and 0.39 t/ha, respectively. Similarly, average annual nutrient export rates are highest for cropland (34.8 kg/ha total nitrogen and 3.3 kg/ha total phosphorus for row crop) in the watershed. Nutrient export rates for pasture land (4.2 kg/ha total nitrogen and 1.5 kg/ha total phosphorus) are significantly greater than range land (2.4 kg/ha total nitrogen and 0.1 kg/ha total phosphorus) due, in part, to the modeled assumption that these are managed pasture lands that receive fertilization from animal manure and commercial fertilizers.

Calculation of average annual loading in terms of kg (or t) per year by land use weights export rates by respective land use area (Table 3.8-15). On an average annual basis, the model predicted that 93% of sediment exported from the basin originated from crop lands (Figure 3.8-22). Other land uses contributing significantly to sediment export based mostly on areal extent were pasture (2.4%) and range (3.5%). Average annual nutrient export by land use follows a similar but slightly less dramatic pattern (Figure 3.8-23). Cropland uses account for 60% of total nitrogen exports, with pasture and range lands contributing 21.3% and 17.1%, respectively. Contributions to average annual total phosphorus export were dominated by

pasture (54%) and crop (40%) land uses. Urban land use export rates (in kg/ha) for sediment and nutrients are generally higher than all land uses other than crop land, but they occupy a small areal fraction of the basin and thus contribute only a small fraction of total average annual sediment and nutrient loading.

Included in Table 3.8-16 are comparisons between SWAT modeled annual average sediment, total nitrogen, and total phosphorus loading delivered to Oologah Lake and estimates of total suspended solids, total nitrogen, and total phosphorus loads developed from regression equations (Section 3.2) at the Verdigris River at Lenapah and Big Creek near Childers. The SWAT model estimates suspended sediment and bed load exported from each modeled subbasin (834,100 t/yr) while the regression estimate (489,330 t/yr) includes just total suspended solids for the 2000-2001 period. SWAT predicted annual average total nitrogen loading (5,688,000 kg/yr) compares reasonably well with the regression estimate of 4,142,800 kg/yr. Modeled annual average total phosphorus load (501,500 kg/yr) also compares favorably with the 616,900 kg/yr regression estimate.

3.8.12 Potential Limitations and Significant Sources of Uncertainty. The SWAT non-point source model of the Oologah Lake watershed is a system of equations that represent a simplification of real processes. Construction of the model and its application requires many assumptions. An essential component of any modeling project is to identify limitations and significant sources of uncertainty. For this application, the following are some issues that may add significantly to uncertainty of predictions:

- Errors in, and scale of, GIS data contribute significantly to uncertainty of modeled output. For example, topographic parameters were estimated using 30-meter resolution elevation data and were averaged over defined subbasins in the watershed. NLCD land use/land cover classifications were based on Thematic Mapper imagery collected from 1988 to 1994. The agency (USGS) accuracy assessment of this data was still pending at the time of data acquisition. For portions of the watershed, soils information was available at 200-meter resolution (as opposed to 30 meter), and thus some important detail may be lost.

Initial soil nutrient concentrations were estimated based on soils database information since detailed soil test nutrient data were not acquired for the various land uses in the watershed.

- The functional modeling units of the SWAT model are combinations of specific land uses and soil types (HRUs) within hydrologically defined subbasins of the larger watershed. In order to reduce the complexity of the model, not every possible combination of land use and soil type is modeled. Rather a data reduction step is performed which identifies combinations of specific land uses accounting for 1% or greater of the subbasin area, with soil types accounting for 10% or greater of the subbasin area. Certain land use/soil combinations, occupying subbasin land area less than these restrictions that may contribute significantly to sediment and nutrient exports, are ignored.
- Weather data input into the model was collected at relatively few points in the basin. Rainfall can be highly variable, and the limited number of weather stations used in this study cannot effectively describe the actual variability.
- Accurate modeling of water bodies (ponds, streams, lakes, and reservoirs) is critically important in accurately determining sediment and nutrient export, and this effort was limited by available information. While relatively good morphometric data was available for reservoirs in the basin, pond areas and pond morphometric data were estimated based on digital land use/land cover data. In-stream and reservoir nutrient dynamics were not modeled. Future revisions of the model may include sediment and nutrient dynamics in streams and reservoirs
- Calibration of sediment and nutrient export has not yet been performed. Collection and manipulation of additional field data to support this type of calibration may be performed in the future.

- The simulation began before the operational dates of four of the five reservoirs in the watershed. Thus, annual average export rates and loading include periods when these reservoirs were not acting as sediment and nutrient traps in the basin. Future applications of the model can be applied to currently existing conditions.
- Point source nutrient inputs were not included in the present modeling effort. This type of information may be included in future revisions of the model.

Table 3.8-1. Land use/cover in the Oologah Lake watershed derived from USGS NLCD and ancillary data and corresponding SWAT model land use codes.

Description	SWAT Land Use Code	Modeled as ...	Area (ha)	Percent Cover
Open Water	---	Reservoirs and ponds	27,931	2.52
Low Intensity Residential	URLD	Urban, low intensity residential	1855	0.17
High Intensity Residential	URHD	Urban, high intensity residential	1561	0.14
Commercial/Industrial/Transportation	UCOM	Urban, commercial and industrial property	1895	0.17
Bare Rock/Sand/Clay	BARE	Bare soil/rock	99	0.01
Quarries/Strip Mines/Gravel Pits	BARE	Bare soil/rock	800	0.07
Transitional	RNGE	Range	528	0.05
Deciduous Forest	FRSD	Deciduous Forest	81,772	7.38
Evergreen Forest	FRSE	Evergreen Forest	2372	0.21
Mixed Forest	FRST	Mixed Forest	6,961	0.63
Shrubland	RNGB	Brushy Range	30,692	2.77
Grasslands/Herbaceous	RNGE	Range	445,080	40.16
Pasture/Hay	PAST	Pasture, managed and/or improved	327,807	29.58
Row Crops	AGRR	Cropland, row crops	108,088	9.75
Small Grains	AGRC	Cropland, close grown	9512	0.86
Urban/Recreational Grasses	BERM	Grass, bermuda	1,213	0.11
Woody Emergents	WETF	Woody wetland	10,035	0.91
Emergent Herbaceous Wetlands	WETN	Herbaceous wetland	11,663	1.05
Roads	ROAD	Roads	38,399	3.47
Total			1,108,263	100

Table 3.8-2. Weather stations in and near the Oologah Lake watershed with daily precipitation and temperature data (1955 – 1999).

Station ID	Elev. (m)	Name	Longitude/Latitude	County, State FIPS
141427	295	Chanute Martin Johnson AP	095:29:00W 37:40:00N	Neosho, KS 20133
142622	323	Eureka	096:17:00W 37:49:00N	Greenwood, KS 20073
142686	299	Fall River Lake	096:05:00W 37:39:00N	Greenwood, KS 20073
142894	264	Fredonia	095:50:00W 37:32:00N	Wilson, KS 20205
143822	336	Howard 5 NE	096:16:00W 37:29:00N	Elk, KS 20049
143954	231	Independence	095:43:00W 37:13:00N	Montgomery, KS 20125
143984	300	Inola 1 W	095:26:00W 37:55:00N	Allen, KS 20001
144812	273	Longton	096:05:00W 37:23:00N	Elk, KS 20049
144937	339	Madison	096:08:00W 38:08:00N	Greenwood, KS 20073
145536	241	Mound Valley 3 WSW	095:27:00W 37:11:00N	Labette, KS 20099
146242	272	Parsons 2 NW	095:16:00W 37:20:00N	Labette, KS 20099
148114	371	Thrall 4 S	096:19:00W 38:01:00N	Greenwood, KS 20073
148436	300	Virgil	096:01:00W 37:59:00N	Greenwood, KS 20073
OK0548	218	Bartlesville Frank Phillips Field	096:00:00W 36:45:00N	Washington, OK 40147
OK4258	277	Hollow	095:16:00W 36:52:00N	Craig, OK 40035
OK5118	227	Lenapah	095:38:00W 36:51:00N	Nowata, OK 40105
OK6485	216	Nowata	095:38:00W 36:42:00N	Nowata, OK 40105

Table 3.8-3. USGS gaging stations in the Oologah Lake watershed.

USGS ID	Name	Lat.	Long.	County	Drainage Area (mi ²)	Period of Record		Notes
						Begin	End	
07165700	Verdigris River Near Madison, KS	38:08:15	96:06:05	Greenwood	181	10/01/55	09/30/76	Above Toronto Lake
07165750	Verdigris River Near Virgil, KS	37:56:31	96:00:48	Greenwood	312	10/01/89	09/30/98	Above Toronto Lake
07166000	Verdigris River Near Coyville, KS	37:42:20	95:54:20	Wilson	747	10/01/30	09/30/98	Below Toronto Lake
07166500	Verdigris River Near Altoona, KS	37:29:26	95:40:49	Wilson	1138	04/01/39	09/30/99	
07167000	Fall River Near Eureka, KS	37:47:07	96:13:52	Greenwood	307	10/01/46	09/30/76	
07167500	Otter Creek At Climax, KS	37:42:30	96:13:30	Greenwood	129	10/01/46	09/30/99	Above Fall River Lake
07168500	Fall River Near Fall River, KS	37:38:34	96:03:33	Greenwood	585	05/01/39	12/31/89	Below Fall River Lake
07169500	Fall River At Fredonia, KS	37:30:30	95:50:00	Wilson	827	10/01/38	09/30/99	
07169800	Elk River At Elk Falls, KS	37:22:32	96:11:07	Elk	220	01/01/67	09/30/99	Above Elk City Lake
07170000	Elk River Near Elk City, KS	37:15:59	95:55:04	Montgomery	575	10/01/38	09/30/69	Above Elk City Lake
07170060	Elk River Below Elk City Lake, KS	37:16:46	95:46:53	Montgomery	634	10/01/65	09/30/99	Below Elk City Lake
07170500	Verdigris River At Independence, KS	37:13:26	95:40:43	Montgomery	2892	10/01/21	09/30/99	
07170700	Big Hill Creek Near Cherryvale, KS	37:16:00	95:28:05	Labette	37	10/01/57	09/30/99	Below Big Hill Lake
07171000	Verdigris River Near Lenapah, OK	36:51:04	95:35:09	Nowata	3639	10/01/38	09/30/99	

Table 3.8-4. USGS 11-Digit HUC watersheds in the Oologah Lake watershed and corresponding SWAT subbasins.

USGS 11-Digit HUC	Area (ha)	Centroid Location		Number of SWAT Subbasins
		Longitude	Latitude	
11070101010	85,527	96:10:20.36W	38:07:02.90N	3
11070101020	32,007	96:10:09.48W	38:00:16.29N	1
11070101046	15,815	95:55:58.08W	37:52:35.09N	1
11070101050	43,308	96:10:18.30W	37:52:16.41N	1
11070101070	21,813	95:56:19.60W	37:43:26.80N	3
11070101080	17,274	95:49:28.39W	37:47:08.04N	1
11070101090	27,443	95:41:04.31W	37:43:02.26N	1
11070101100	34,681	95:44:44.93W	37:34:50.35N	2
11070101110	12,270	95:35:30.80W	37:34:11.26N	1
11070101120	14,304	95:33:15.40W	37:29:40.00N	1
11070102010	81,302	96:25:42.16W	37:53:33.16N	1
11070102020	38,857	96:21:33.12W	37:41:24.50N	2
11070102030	22,702	96:08:23.20W	37:42:51.88N	1
11070102040	41,802	96:05:55.44W	37:35:46.09N	1
11070102050	37,393	95:51:04.55W	37:30:00.92N	2
11070103010	8,163	95:35:27.51W	37:25:27.97N	1
11070103020	42,096	95:40:06.69W	37:13:30.83N	2
11070103030	23,180	95:32:22.46W	37:19:29.76N	1
11070103031	41,026	95:37:59.87W	36:49:24.67N	1
11070103040	31,632	95:30:31.47W	37:13:55.86N	4
11070103041	43,730	95:20:28.35W	36:52:34.91N	1
11070103050	37,694	95:25:42.67W	37:08:37.50N	1
11070103051	89,475	95:34:11.78W	36:37:25.73N	1
11070103065	29,083	95:45:30.22W	37:05:15.23N	1
11070103073	42,831	95:36:17.02W	36:57:43.65N	1
11070104010	56,731	96:20:12.21W	37:30:20.77N	1
11070104020	51,871	96:08:00.14W	37:24:04.41N	1
11070104030	15,740	95:52:59.92W	37:22:52.19N	1
11070104040	16,638	95:45:59.40W	37:19:41.73N	1
11070104041	39,670	95:57:50.69W	37:16:30.74N	2

Table 3.8-5. Pertinent data for USACE reservoirs in the Oologah Lake watershed.

Lake Name	Operational Date	Area Flood Pool (ha)	Volume Flood Pool (ha-m)	Area Conservation Pool (ha)	Volume Conservation Pool (ha-m)	Municipal Water Use (ha-m/mon)
Oologah Lake	May-63	27,163	192,415	12,562	68,144	1749.06
Toronto Lake	Mar-60	4,751	24,784	1,077	2,595	1.14
Fall River Lake	Apr-49	4,201	31,452	943	2,792	0.00
Elk City Lake	Mar-66	5,806	35,102	1,797	5,368	113.58
Big Hill Lake	Mar-81	597	4,879	482	3,328	96.54

Data from USACE (1993) and USACE (2001).

Table 3.8-6. Livestock inventory estimates in counties within the Oologah Lake watershed.

County	FIPS Code	Cattle/calves Inventory ¹	Hogs/pigs Inventory ¹	Sheep/lambs Inventory ¹	Layers/Pullets Inventory ¹	Broilers/other Inventory ¹
Butler	20015	121,627	43,990	4,280	6,668	---
Chase	20017	60,998	7,640	372	429	---
Chautauqua	20019	47,545	3,097	250	520	---
Coffey	20031	34,424	7,683	2,613	---	---
Elk	20049	44,240	5,280	443	957	---
Greenwood	20073	85,624	2,228	647	731	---
Labette	20099	60,067	6,620	836	550	---
Lyon	20111	69,375	8,493	992	29,689	---
Montgomery	20125	38,559	26,842	834	859	---
Neosho	20133	45,358	15,025	1,072	697	---
Wilson	20205	31,432	10,289	1,248	307	---
Woodson	20207	48,495	2,230	919	255	---
Craig	40035	100,801	854	555	1,254	3,420,005
Nowata	40105	59,699	637	264	745	---
Rogers	40131	62,214	847	273	2,550	830
Washington	40147	34,393	1,224	258	675	---

¹ Average of 1992 and 1997 USDA-NASS data (1997).

Table 3.8-7. Animal waste characterization.*

	Beef Per 1000 kg	Swine Per 1000 kg	Sheep Per 1000 kg	Poultry Per 1000 kg
Average Animal Weight (kg)	420	50	27	1
Manure Weight (kg/d)	58	80.5	40	82
Nitrogen as N (kg/d)	0.32	0.45	0.45	1.1
Phosphorus as P (kg/d)	0.098	0.135	0.08	0.32
N Available (Fraction)	0.5	0.25	0.5	1
P Available (Fraction)	1	1	1	1

* Data from Lander and Moffit (1998), USDA-SCS (1992), and ASAE (1991).

Table 3.8-8. Estimates of livestock generated nitrogen and phosphorus applied to crop and pasture land for counties within the Oologah Lake watershed.

County	FIPS Code	Crop & Pasture Area (ha)	Animal Nitrogen Applied (kg/ha/yr)	Animal Phosphorus Applied (kg/ha/yr)
Butler	20015	130,719	23.59	14.83
Chase	20017	34,159	44.26	27.37
Chautauqua	20019	25,988	45.12	27.77
Coffey	20031	84,299	10.27	6.38
Elk	20049	32,758	33.48	20.69
Greenwood	20073	60,582	34.75	21.32
Labette	20099	89,559	16.62	10.26
Lyon	20111	105,761	16.37	10.08
Montgomery	20125	74,909	13.38	8.62
Neosho	20133	85,762	13.36	8.38
Wilson	20205	71,734	11.08	6.95
Woodson	20207	51,838	23.06	14.17
Craig	40035	68,318	54.47	27.50
Nowata	40105	39,555	37.05	22.71
Rogers	40131	49,647	30.79	18.87
Washington	40147	27,406	30.89	18.96

Table 3.8-9. Estimates of rates of commercial fertilizer applications for counties included in the Oologah Lake watershed.

County	FIPS Code	¹ Crop & Pasture Area (ha)	² Nitrogen (kg/yr)	² Phosphorus (kg/yr)	Nitrogen (kg/ha/yr)	Phosphorus (kg/ha/yr)
Butler	20015	130,719	6,496,285	820,691	49.70	6.28
Chase	20017	34,159	1,210,652	152,945	35.44	4.48
Chautauqua	20019	25,988	1,499,631	189,452	57.70	7.29
Coffey	20031	84,299	2,933,967	370,655	34.80	4.40
Elk	20049	32,758	1,298,898	164,093	39.65	5.01
Greenwood	20073	60,582	1,932,727	244,166	31.90	4.03
Labette	20099	89,559	5,876,301	742,367	65.61	8.29
Lyon	20111	105,761	3,697,330	467,092	34.96	4.42
Montgomery	20125	74,909	5,154,733	651,209	68.81	8.69
Neosho	20133	85,762	3,780,767	477,633	44.08	5.57
Wilson	20205	71,734	3,844,497	265,559	53.59	3.70
Woodson	20207	51,838	2,102,064	265,559	40.55	5.12
Craig	40035	68,318	2,274,960	367,518	33.30	5.38
Nowata	40105	39,555	1,227,458	198,295	31.03	5.01
Rogers	40131	49,647	1,050,528	169,712	21.16	3.42
Washington	40147	27,406	1,118,500	180,693	40.81	6.59

¹ Average of 1992 and 1997 USDA-NASS data (1997).

² 1985 estimates from Alexander and Smith (1990).

Table 3.8-10. SWAT hydrologic calibration results at six USGS gaging stations with unregulated flow in the Oologah Lake watershed.

USGS Gage	Comparison Period of Record	Compared Flow	Measured Annual Mean (cms)	SWAT Annual Mean (cms)	Annual Correlation	Relative Annual Difference (%)
07165700	1956 - 1975	Total Flow	3.64	3.73	0.95	2.39
		Base Flow	0.74	0.72	0.77	-3.31
		Surface Flow	2.90	3.00	0.97	3.48
07165750	1990 - 1997	Total Flow	5.61	5.50	0.94	-1.90
		Base Flow	1.14	1.08	0.90	-5.91
		Surface Flow	4.47	4.44	0.93	-0.66
07167000	1955 - 1975	Total Flow	5.69	5.55	0.94	-2.44
		Base Flow	1.49	1.42	0.86	-4.28
		Surface Flow	4.20	4.14	0.93	-1.46
07167500	1955 - 1998	Total Flow	2.33	2.43	0.85	4.24
		Base Flow	0.40	0.42	0.79	3.22
		Surface Flow	1.92	2.00	0.79	3.84
07169800	1967 - 1998	Total Flow	4.27	4.19	0.86	-1.86
		Base Flow	0.72	0.77	0.78	6.65
		Surface Flow	3.55	3.43	0.81	-3.22
07170000	1955 - 1968	Total Flow	6.99	7.22	0.98	3.24
		Base Flow	0.89	0.84	0.75	-5.56
		Surface Flow	6.11	6.22	0.96	1.95

Table 3.8-11. Comparisons of measured and simulated mean annual discharge at USGS gaging stations with regulated flows.

USGS Gage ID	Comparison Period of Record	Measured Annual Mean (cms)	SWAT Annual Mean (cms)	Annual Correlation	Relative Annual Difference (%)
07166000	1955 - 1997	14.21	15.36	0.96	8.09
07166500	1955 - 1998	21.98	24.08	0.97	9.59
07168500	1955 - 1989	9.74	10.63	0.92	9.16
07169500	1955 - 1998	14.71	11.26	0.93	-23.48
07170060	1966 - 1998	12.96	14.01	0.96	8.14
07170500	1955 - 1998	55.73	54.64	0.98	-1.97
07170700	1958 - 1998	0.77	0.72	0.87	-6.41
07171000	1955 - 1998	71.46	72.10	0.98	0.89

Table 3.8-12. Estimated sediment and nutrient yields by 11-digit HUC in the Oologah Lake watershed.

11-Digit HUC	Area (ha)		Sediment Yield (t/ha)	Organic Nitrogen (kg/ha)	Nitrate in Surface Runoff (kg/ha)	Soluble Phosphorus (kg/ha)	Sediment Bound Phosphorus (kg/ha)
11070101010	85,527	Mean	4.68	4.80	0.88	0.20	0.42
		St. Dev.	2.66	2.86	0.46	0.13	0.26
		25th Percentile	3.34	3.34	0.62	0.12	0.30
		Median	4.45	4.47	0.88	0.18	0.38
		75th Percentile	5.40	5.69	1.05	0.26	0.53
		Minimum	0.86	0.87	0.16	0.01	0.06
		Maximum	12.87	18.36	2.10	0.61	1.59
		N	45	45	45	45	45
11070101020	32,007	Mean	6.33	5.94	1.13	0.22	0.52
		St. Dev.	3.18	3.54	0.45	0.13	0.31
		25th Percentile	4.97	4.35	0.80	0.11	0.39
		Median	5.93	5.29	1.07	0.22	0.49
		75th Percentile	7.48	6.55	1.37	0.29	0.60
		Minimum	1.15	1.16	0.36	0.02	0.09
		Maximum	20.62	24.06	2.37	0.71	2.12
		N	45	45	45	45	45
11070101046	15,815	Mean	6.39	5.14	1.30	0.34	0.55
		St. Dev.	3.97	3.94	0.61	0.22	0.39
		25th Percentile	4.56	3.57	0.83	0.15	0.36
		Median	5.57	4.37	1.21	0.34	0.50
		75th Percentile	7.54	5.70	1.62	0.46	0.66
		Minimum	0.83	0.70	0.19	0.01	0.06
		Maximum	24.09	27.44	2.93	1.14	2.56
		N	45	45	45	45	45
11070101050	43,308	Mean	3.52	4.41	1.04	0.24	0.38
		St. Dev.	1.71	2.67	0.53	0.15	0.18
		25th Percentile	2.61	3.10	0.63	0.10	0.24
		Median	3.40	4.02	0.91	0.22	0.37
		75th Percentile	3.96	5.23	1.28	0.33	0.48
		Minimum	0.53	1.16	0.19	0.01	0.06
		Maximum	8.26	17.25	2.70	0.65	0.85
		N	45	45	45	45	45
11070101070	21,813	Mean	3.79	4.41	1.17	0.29	0.41
		St. Dev.	2.07	2.04	0.68	0.21	0.22
		25th Percentile	2.26	2.85	0.60	0.13	0.23
		Median	3.28	3.99	1.02	0.21	0.37
		75th Percentile	5.26	6.04	1.55	0.52	0.60
		Minimum	0.66	0.97	0.23	0.01	0.07
		Maximum	8.77	8.26	2.92	0.73	0.84
		N	45	45	45	45	45

Table 3.8-12 (Continued)

11-Digit HUC	Area (ha)		Sediment Yield (t/ha)	Organic Nitrogen (kg/ha)	Nitrate in Surface Runoff (kg/ha)	Soluble Phosphorus (kg/ha)	Sediment Bound Phosphorus (kg/ha)
11070101080	17,274	Mean	6.67	4.58	0.74	0.19	0.45
		St. Dev.	3.76	2.07	0.41	0.14	0.23
		25th Percentile	3.64	2.85	0.44	0.08	0.27
		Median	6.00	4.05	0.69	0.14	0.39
		75th Percentile	9.56	6.54	1.02	0.31	0.61
		Minimum	1.08	1.10	0.12	0.01	0.09
		Maximum	15.50	9.66	1.65	0.57	0.92
		N	45	45	45	45	45
11070101090	27,443	Mean	16.42	8.89	1.23	0.32	0.74
		St. Dev.	6.87	3.70	0.59	0.24	0.34
		25th Percentile	12.14	6.70	0.70	0.16	0.51
		Median	15.39	9.02	1.18	0.27	0.69
		75th Percentile	20.51	10.55	1.65	0.41	0.94
		Minimum	4.07	3.05	0.32	0.02	0.20
		Maximum	31.08	21.62	2.63	0.82	1.55
		N	45	45	45	45	45
11070101100	34,681	Mean	6.98	6.62	0.88	0.24	0.56
		St. Dev.	4.39	3.39	0.44	0.17	0.31
		25th Percentile	4.09	3.93	0.58	0.10	0.32
		Median	6.78	6.60	0.85	0.20	0.62
		75th Percentile	9.48	9.22	1.18	0.37	0.76
		Minimum	0.02	0.08	0.11	0.00	0.00
		Maximum	18.17	12.81	1.70	0.74	1.29
		N	45	45	45	45	45
11070101110	12,270	Mean	14.02	10.27	2.23	0.68	0.91
		St. Dev.	6.01	4.33	1.06	0.42	0.39
		25th Percentile	10.89	7.91	1.32	0.38	0.68
		Median	13.25	10.32	2.28	0.57	0.87
		75th Percentile	17.34	12.06	2.97	0.96	1.12
		Minimum	3.02	3.44	0.63	0.04	0.24
		Maximum	26.65	23.26	4.69	1.58	1.72
		N	45	45	45	45	45
11070101120	14,304	Mean	7.11	7.03	1.07	0.38	0.59
		St. Dev.	3.52	3.28	0.60	0.26	0.29
		25th Percentile	4.74	5.05	0.55	0.21	0.39
		Median	6.60	7.15	0.96	0.31	0.60
		75th Percentile	8.91	9.00	1.52	0.50	0.72
		Minimum	1.23	1.67	0.21	0.02	0.12
		Maximum	15.17	18.04	2.62	0.93	1.22
		N	45	45	45	45	45

Table 3.8-12 (Continued)

11-Digit HUC	Area (ha)		Sediment Yield (t/ha)	Organic Nitrogen (kg/ha)	Nitrate in Surface Runoff (kg/ha)	Soluble Phosphorus (kg/ha)	Sediment Bound Phosphorus (kg/ha)
11070102010	81,302	Mean	1.62	2.55	0.73	0.15	0.23
		St. Dev.	1.17	2.05	0.47	0.12	0.15
		25th Percentile	0.75	1.19	0.41	0.06	0.10
		Median	1.46	2.35	0.63	0.13	0.23
		75th Percentile	2.16	2.96	0.98	0.22	0.31
		Minimum	0.09	0.20	0.06	0.00	0.01
		Maximum	6.26	12.09	1.88	0.52	0.72
		N	45	45	45	45	45
11070102020	38,857	Mean	3.35	4.59	1.01	0.27	0.39
		St. Dev.	1.75	2.86	0.56	0.18	0.19
		25th Percentile	2.39	3.07	0.61	0.15	0.26
		Median	3.07	4.30	0.91	0.25	0.39
		75th Percentile	3.84	5.34	1.18	0.35	0.51
		Minimum	0.36	0.72	0.20	0.01	0.04
		Maximum	9.13	18.05	2.82	0.73	0.89
		N	45	45	45	45	45
11070102030	22,702	Mean	7.02	5.88	1.03	0.23	0.55
		St. Dev.	3.42	2.33	0.52	0.15	0.24
		25th Percentile	4.64	4.10	0.62	0.11	0.39
		Median	6.26	5.88	0.91	0.19	0.51
		75th Percentile	9.34	7.80	1.36	0.34	0.75
		Minimum	1.67	1.63	0.21	0.02	0.13
		Maximum	14.62	12.14	2.04	0.56	1.09
		N	45	45	45	45	45
11070102040	41,802	Mean	7.52	5.61	1.51	0.33	0.51
		St. Dev.	3.54	2.02	0.91	0.21	0.20
		25th Percentile	5.27	4.18	0.79	0.17	0.36
		Median	6.68	5.59	1.54	0.28	0.48
		75th Percentile	10.40	7.14	1.98	0.51	0.70
		Minimum	1.48	1.71	0.33	0.02	0.15
		Maximum	15.57	10.70	3.88	0.80	1.02
		N	45	45	45	45	45
11070102050	37,393	Mean	8.06	6.16	0.83	0.23	0.59
		St. Dev.	4.76	3.07	0.43	0.17	0.32
		25th Percentile	5.42	4.02	0.60	0.11	0.36
		Median	8.15	6.19	0.75	0.21	0.59
		75th Percentile	10.33	8.36	1.09	0.35	0.83
		Minimum	0.07	0.19	0.11	0.00	0.01
		Maximum	20.10	12.04	1.71	0.69	1.33
		N	45	45	45	45	45

Table 3.8-12 (Continued)

11-Digit HUC	Area (ha)		Sediment Yield (t/ha)	Organic Nitrogen (kg/ha)	Nitrate in Surface Runoff (kg/ha)	Soluble Phosphorus (kg/ha)	Sediment Bound Phosphorus (kg/ha)
11070103010	8,163	Mean	6.85	6.76	0.98	0.29	0.57
		St. Dev.	3.86	3.21	0.47	0.19	0.29
		25th Percentile	4.49	4.21	0.73	0.14	0.35
		Median	6.84	6.28	0.95	0.27	0.63
		75th Percentile	9.42	9.06	1.19	0.43	0.79
		Minimum	0.16	0.43	0.11	0.01	0.02
		Maximum	16.84	12.95	2.03	0.82	1.28
		N	45	45	45	45	45
11070103020	42,096	Mean	5.55	5.77	0.96	0.35	0.55
		St. Dev.	2.72	2.37	0.50	0.24	0.25
		25th Percentile	3.90	4.27	0.58	0.19	0.39
		Median	5.32	5.69	0.91	0.34	0.55
		75th Percentile	7.03	7.35	1.29	0.45	0.70
		Minimum	0.45	0.96	0.08	0.01	0.05
		Maximum	14.41	10.49	2.37	1.04	1.30
		N	45	45	45	45	45
11070103030	23,180	Mean	6.38	6.44	1.29	0.49	0.67
		St. Dev.	2.82	2.68	0.73	0.32	0.30
		25th Percentile	5.03	4.95	0.79	0.25	0.47
		Median	6.21	6.43	1.19	0.42	0.66
		75th Percentile	7.11	8.15	1.61	0.70	0.83
		Minimum	0.85	1.29	0.18	0.01	0.09
		Maximum	14.08	14.25	3.49	1.20	1.43
		N	45	45	45	45	45
11070103031	41,026	Mean	1.82	2.40	1.50	0.53	0.33
		St. Dev.	1.72	2.66	0.83	0.36	0.24
		25th Percentile	0.99	1.21	0.99	0.26	0.16
		Median	1.49	1.80	1.38	0.45	0.27
		75th Percentile	2.19	2.87	1.89	0.70	0.48
		Minimum	0.25	0.28	0.26	0.02	0.02
		Maximum	11.60	17.98	3.82	1.66	1.05
		N	45	45	45	45	45
11070103040	31,632	Mean	6.92	6.16	1.51	0.49	0.69
		St. Dev.	2.93	2.30	0.78	0.30	0.29
		25th Percentile	5.43	4.64	0.94	0.25	0.53
		Median	6.75	6.45	1.46	0.43	0.67
		75th Percentile	8.36	7.52	2.00	0.72	0.84
		Minimum	0.91	1.17	0.30	0.02	0.10
		Maximum	13.83	11.03	3.77	1.16	1.36
		N	45	45	45	45	45

Table 3.8-12 (Continued)

11-Digit HUC	Area (ha)		Sediment Yield (t/ha)	Organic Nitrogen (kg/ha)	Nitrate in Surface Runoff (kg/ha)	Soluble Phosphorus (kg/ha)	Sediment Bound Phosphorus (kg/ha)
11070103041	43,730	Mean	3.10	3.75	1.37	0.44	0.49
		St. Dev.	1.44	2.38	0.60	0.26	0.21
		25th Percentile	2.32	2.80	0.88	0.27	0.38
		Median	2.85	3.49	1.25	0.43	0.46
		75th Percentile	3.70	4.19	1.80	0.55	0.64
		Minimum	0.32	0.44	0.48	0.04	0.05
		Maximum	8.37	16.95	3.14	1.33	1.13
		N	45	45	45	45	45
11070103050	37,694	Mean	9.90	8.01	3.80	1.07	0.95
		St. Dev.	3.74	3.05	1.66	0.57	0.35
		25th Percentile	8.10	6.60	2.57	0.60	0.73
		Median	9.91	7.68	3.86	1.05	0.95
		75th Percentile	11.58	9.63	4.97	1.51	1.08
		Minimum	2.07	2.48	1.16	0.06	0.20
		Maximum	19.29	19.89	8.03	2.18	1.78
		N	45	45	45	45	45
11070103051	89,475	Mean	0.31	1.26	1.32	0.56	0.19
		St. Dev.	0.68	1.33	0.85	0.41	0.15
		25th Percentile	0.09	0.47	0.73	0.23	0.07
		Median	0.17	0.91	1.13	0.47	0.15
		75th Percentile	0.30	1.60	1.85	0.76	0.25
		Minimum	0.02	0.07	0.14	0.01	0.00
		Maximum	4.70	8.40	3.92	1.84	0.69
		N	45	45	45	45	45
11070103065	29,083	Mean	4.18	4.99	1.10	0.42	0.51
		St. Dev.	2.03	1.97	0.62	0.29	0.23
		25th Percentile	2.93	3.78	0.67	0.19	0.36
		Median	4.12	5.05	1.03	0.38	0.52
		75th Percentile	5.24	6.17	1.55	0.56	0.63
		Minimum	0.39	1.02	0.10	0.01	0.05
		Maximum	10.83	9.43	2.94	1.20	1.18
		N	45	45	45	45	45
11070103073	42,831	Mean	3.47	3.79	1.67	0.58	0.50
		St. Dev.	1.99	2.52	0.87	0.37	0.27
		25th Percentile	1.98	2.49	1.13	0.33	0.31
		Median	3.18	3.18	1.55	0.52	0.47
		75th Percentile	4.73	4.59	1.97	0.77	0.68
		Minimum	0.22	0.50	0.32	0.03	0.03
		Maximum	8.12	15.09	4.46	1.74	1.21
		N	45	45	45	45	45

Table 3.8-12 (Continued)

11-Digit HUC	Area (ha)		Sediment Yield (t/ha)	Organic Nitrogen (kg/ha)	Nitrate in Surface Runoff (kg/ha)	Soluble Phosphorus (kg/ha)	Sediment Bound Phosphorus (kg/ha)
11070104010	56,731	Mean	4.15	4.43	0.88	0.26	0.49
		St. Dev.	2.26	2.23	0.51	0.18	0.26
		25th Percentile	2.44	2.46	0.50	0.14	0.27
		Median	3.67	4.19	0.76	0.19	0.38
		75th Percentile	5.48	5.94	1.20	0.37	0.67
		Minimum	0.20	0.38	0.20	0.00	0.02
		Maximum	10.30	9.66	2.07	0.71	1.04
		N	45	45	45	45	45
11070104020	51,871	Mean	2.90	3.39	1.30	0.39	0.44
		St. Dev.	1.76	1.74	0.69	0.26	0.27
		25th Percentile	1.49	2.15	0.70	0.18	0.24
		Median	2.49	3.01	1.18	0.33	0.41
		75th Percentile	3.74	4.55	1.80	0.54	0.61
		Minimum	0.21	0.45	0.26	0.01	0.03
		Maximum	7.41	7.01	3.05	1.09	1.13
		N	45	45	45	45	45
11070104030	15,740	Mean	13.14	7.36	1.28	0.31	0.71
		St. Dev.	6.50	2.80	0.66	0.23	0.34
		25th Percentile	8.28	5.15	0.76	0.13	0.43
		Median	12.58	7.35	1.22	0.22	0.65
		75th Percentile	17.06	8.86	1.61	0.45	0.87
		Minimum	2.02	2.38	0.32	0.01	0.18
		Maximum	28.95	13.57	2.80	0.91	1.49
		N	45	45	45	45	45
11070104040	16,638	Mean	9.27	6.72	1.26	0.30	0.60
		St. Dev.	3.89	2.81	0.57	0.20	0.24
		25th Percentile	7.14	5.32	0.85	0.14	0.48
		Median	9.73	6.23	1.22	0.30	0.60
		75th Percentile	11.26	7.89	1.61	0.38	0.73
		Minimum	1.22	1.97	0.21	0.01	0.10
		Maximum	20.50	19.19	2.73	0.81	1.31
		N	45	45	45	45	45
11070104041	39,670	Mean	7.82	6.23	1.80	0.51	0.79
		St. Dev.	3.79	2.46	0.89	0.32	0.39
		25th Percentile	5.36	4.34	1.00	0.23	0.49
		Median	7.99	6.55	1.69	0.48	0.76
		75th Percentile	10.14	7.87	2.45	0.69	1.03
		Minimum	0.76	1.26	0.44	0.02	0.07
		Maximum	18.68	11.00	3.49	1.31	1.72
		N	45	45	45	45	45

Table 3.8-13. Estimated sediment and nutrient loading by land use by 11-digit HUC.

11-Digit HUC	Land Use	Area (ha)	Percent Area	Surface Runoff (mm)	Sediment Yield (t/ha)	Organic Nitrogen As N (kg/ha)	Nitrate As N (kg/ha)	Soluble Phosphorus As P (kg/ha)	Sediment-Bound Phosphorus As P (kg/ha)
11070101010	Cropland, Row	7,920	9.3	315.98	46.89	37.97	1.41	0.25	3.48
	Forest, Deciduous	2,041	2.4	89.29	0.06	0.23	0.20	0.00	0.01
	Pasture	13,627	15.9	172.90	0.94	2.88	2.04	0.94	0.51
	Range, Brushy	1,936	2.3	190.50	0.41	2.38	0.51	0.08	0.07
	Range	56,977	66.6	217.19	0.26	1.15	0.55	0.03	0.03
	Roads	2,946	3.4	409.36	0.27	0.03	1.29	0.07	0.03
	Wetland, Woody	79	0.1	97.82	0.05	0.19	0.21	0.00	0.01
Total Area & Subbasin Averages		85,527	100.0	222.14	4.68	4.80	0.88	0.20	0.42
11070101020	Cropland, Row	3,200	10.0	411.48	57.17	39.19	2.43	0.26	3.78
	Forest, Deciduous	997	3.1	108.47	0.07	0.19	0.25	0.00	0.01
	Pasture	5,235	16.4	187.19	1.56	3.90	2.44	1.02	0.66
	Range, Brushy	1,149	3.6	202.60	0.40	2.07	0.56	0.08	0.06
	Range	20,090	62.8	251.07	0.53	2.07	0.65	0.03	0.05
	Roads	1,336	4.2	401.21	0.22	0.03	1.27	0.07	0.03
Total Area & Subbasin Averages		32,007	100.0	256.74	6.33	5.94	1.13	0.22	0.52
11070101046	Cropland, Row	1,296	8.2	300.28	67.02	33.41	1.49	0.21	3.67
	Forest, Deciduous	978	6.2	117.44	0.12	0.25	0.27	0.00	0.01
	Pasture	4,980	31.5	193.01	1.66	3.52	2.51	0.97	0.68
	Range, Brushy	573	3.6	153.55	0.39	1.74	0.38	0.06	0.06
	Range	7,383	46.7	273.19	0.73	2.60	0.69	0.02	0.07
	Roads	433	2.7	401.04	0.25	0.03	1.25	0.07	0.03
	Wetland, Woody	174	1.1	78.43	0.05	0.22	0.17	0.00	0.01
Total Area & Subbasin Averages		15,816	100.0	237.57	6.39	5.14	1.30	0.34	0.55
11070101050	Cropland, Row	3,171	7.3	377.38	42.86	40.54	2.10	0.27	3.50
	Forest, Deciduous	720	1.7	92.16	0.07	0.22	0.21	0.00	0.01
	Pasture	9,490	21.9	178.69	0.53	2.35	2.11	0.92	0.44
	Range, Brushy	1,713	4.0	184.38	0.40	1.84	0.49	0.07	0.05
	Range	26,495	61.2	231.44	0.38	1.35	0.59	0.03	0.04
	Roads	1,251	2.9	407.15	0.20	0.02	1.25	0.07	0.02
	Wetland, Herbaceous	469	1.1	220.40	0.42	2.04	0.49	0.01	0.03
Total Area & Subbasin Averages		43,308	100.0	231.35	3.52	4.41	1.04	0.24	0.38

Table 3.8-13. (Continued)

11-Digit HUC	Land Use	Area (ha)	Percent Area	Surface Runoff (mm)	Sediment Yield (t/ha)	Organic Nitrogen As N (kg/ha)	Nitrate As N (kg/ha)	Soluble Phosphorus As P (kg/ha)	Sediment-Bound Phosphorus As P (kg/ha)
11070101070	Cropland, Row	1,895	8.7	274.92	40.35	34.28	1.36	0.18	3.02
	Forest, Deciduous	2,639	12.1	182.36	0.05	0.06	0.45	0.00	0.01
	Forest, Mixed	88	0.4	113.40	0.02	0.06	0.26	0.00	0.00
	Pasture	5,959	27.3	149.81	0.28	1.97	2.50	0.95	0.48
	Range, Brushy	471	2.2	173.57	0.22	0.99	0.43	0.03	0.03
	Range	9,292	42.6	222.65	0.42	1.94	0.58	0.03	0.04
	Roads	779	3.6	385.67	0.23	0.03	1.19	0.07	0.03
	Wetland, Woody	346	1.6	111.71	0.07	0.26	0.27	0.00	0.01
	Wetland, Herbaceous	346	1.6	223.26	0.45	2.24	0.52	0.01	0.04
Total Area & Subbasin Averages		21,814	100.0	204.99	3.78	4.41	1.17	0.29	0.41
11070101080	Cropland, Row	1,880	10.9	278.96	58.56	31.03	1.36	0.17	2.97
	Forest, Deciduous	3,442	19.9	181.17	0.10	0.10	0.43	0.00	0.01
	Pasture	5,743	33.2	98.54	0.26	1.46	0.93	0.49	0.33
	Range, Brushy	483	2.8	131.43	0.24	0.87	0.32	0.03	0.03
	Range	5,121	29.6	211.94	0.58	2.25	0.50	0.02	0.05
	Roads	605	3.5	385.74	0.27	0.03	1.16	0.07	0.03
Total Area & Subbasin Averages		17,274	100.0	179.24	6.67	4.58	0.74	0.19	0.45
11070101090	Cropland, Row	5,328	19.4	476.77	82.41	34.76	2.81	0.15	2.54
	Forest, Deciduous	1,681	6.1	117.02	0.14	0.40	0.26	0.00	0.01
	Pasture	10,609	38.7	123.05	0.37	2.52	0.92	0.71	0.57
	Range, Brushy	599	2.2	205.18	0.47	2.06	0.49	0.05	0.06
	Range	7,882	28.7	316.56	0.81	3.63	0.82	0.05	0.09
	Roads	969	3.5	490.80	0.34	0.04	1.56	0.08	0.04
	Wetland, Herbaceous	375	1.4	338.72	0.86	3.86	0.78	0.02	0.07
Total Area & Subbasin Averages		27,443	100.0	264.65	16.42	8.89	1.23	0.32	0.74
11070101100	Cropland, Close Grown	500	1.4	249.42	4.83	11.67	0.89	0.19	1.09
	Cropland, Row	6,621	19.1	256.13	35.10	28.24	1.04	0.16	2.28
	Forest, Deciduous	3,970	11.4	173.92	0.09	0.31	0.39	0.00	0.01
	Forest, Mixed	615	1.8	132.37	0.08	0.29	0.29	0.00	0.01
	Pasture	11,479	33.1	97.12	0.17	1.18	0.99	0.54	0.28
	Range, Brushy	586	1.7	204.76	0.36	1.24	0.48	0.02	0.04
	Range	9,477	27.3	308.26	0.44	2.19	0.87	0.07	0.06
	Roads	1,365	3.9	413.98	0.27	0.03	1.22	0.07	0.03
	Wetland, Herbaceous	68	0.2	352.37	0.65	2.91	0.73	0.01	0.05
Total Area & Subbasin Averages		34,681	100.0	211.58	6.98	6.62	0.88	0.24	0.56

Table 3.8-13. (Continued)

11-Digit HUC	Land Use	Area (ha)	Percent Area	Surface Runoff (mm)	Sediment Yield (t/ha)	Organic Nitrogen As N (kg/ha)	Nitrate As N (kg/ha)	Soluble Phosphorus As P (kg/ha)	Sediment-Bound Phosphorus As P (kg/ha)
11070101110	Cropland, Close Grown	220	1.8	451.58	7.36	14.39	2.00	0.31	1.39
	Cropland, Row	2,917	23.8	473.08	56.77	32.61	2.90	0.18	2.39
	Forest, Deciduous	636	5.2	178.02	0.14	0.47	0.41	0.01	0.01
	Pasture	4,905	40.0	238.81	0.51	3.42	2.98	1.49	0.73
	Range	2,950	24.0	345.90	0.67	3.42	0.93	0.11	0.09
	Roads	494	4.0	490.48	0.23	0.03	1.55	0.08	0.03
	Wetland, Herbaceous	148	1.2	408.74	0.70	3.58	0.94	0.03	0.06
Total Area & Subbasin Averages		12,270	100.0	333.09	14.02	10.27	2.23	0.68	0.91
11070101120	Cropland, Row	3,045	21.3	320.76	32.31	27.20	1.46	0.15	2.07
	Forest, Deciduous	1,629	11.4	114.77	0.07	0.14	0.24	0.00	0.01
	Pasture	6,073	42.5	139.95	0.22	1.47	1.20	0.76	0.30
	Range	2,728	19.1	301.13	0.63	3.03	0.77	0.10	0.08
	Roads	607	4.2	490.35	0.22	0.03	1.53	0.08	0.02
	Wetland, Herbaceous	223	1.6	231.03	0.30	1.01	0.49	0.01	0.03
Total Area & Subbasin Averages		14,304	100.0	222.60	7.11	7.03	1.07	0.38	0.59
11070102010	Cropland, Row	2,247	2.8	227.04	46.20	42.79	0.87	0.20	3.76
	Pasture	12,546	15.4	136.87	0.74	3.33	2.03	0.80	0.66
	Range, Brushy	3,797	4.7	128.89	0.53	2.28	0.37	0.06	0.07
	Range	59,439	73.1	180.55	0.26	0.97	0.47	0.02	0.02
	Roads	2,440	3.0	371.27	0.33	0.04	1.17	0.07	0.04
	Wetland, Herbaceous	833	1.0	194.75	0.70	3.25	0.43	0.01	0.05
Total Area & Subbasin Averages		81,302	100.0	178.55	1.62	2.55	0.73	0.15	0.23
11070102020	Cropland, Row	2,327	6.0	354.97	48.19	40.20	1.98	0.25	3.77
	Forest, Deciduous	874	2.2	92.22	0.11	0.31	0.21	0.00	0.01
	Pasture	8,893	22.9	147.02	0.48	2.73	1.89	0.93	0.53
	Range, Brushy	2,778	7.1	183.17	0.48	2.02	0.46	0.03	0.05
	Range	22,284	57.3	222.99	0.53	2.38	0.65	0.07	0.06
	Roads	1,097	2.8	409.78	0.24	0.03	1.30	0.07	0.03
	Wetland, Herbaceous	605	1.6	239.24	0.61	2.89	0.55	0.01	0.05
Total Area & Subbasin Averages		38,857	100.0	213.24	3.35	4.59	1.01	0.27	0.39
11070102030	Cropland, Row	2,817	12.4	354.14	54.52	37.52	1.83	0.26	3.65
	Forest, Deciduous	1,243	5.5	107.70	0.05	0.19	0.24	0.00	0.01
	Pasture	4,292	18.9	177.14	0.34	2.02	2.36	0.94	0.41
	Range, Brushy	1,188	5.2	163.14	0.25	1.45	0.43	0.06	0.04
	Range	12,021	53.0	213.51	0.32	1.42	0.52	0.02	0.03
	Roads	733	3.2	387.84	0.24	0.03	1.16	0.07	0.03
	Wetland, Woody	408	1.8	91.89	0.06	0.23	0.20	0.00	0.01
Total Area & Subbasin Averages		22,702	100.0	219.10	7.02	5.88	1.03	0.23	0.55

Table 3.8-13. (Continued)

11-Digit HUC	Land Use	Area (ha)	Percent Area	Surface Runoff (mm)	Sediment Yield (t/ha)	Organic Nitrogen As N (kg/ha)	Nitrate As N (kg/ha)	Soluble Phosphorus As P (kg/ha)	Sediment-Bound Phosphorus As P (kg/ha)
11070102040	Cropland, Row	5,118	12.2	384.45	60.09	39.38	2.53	0.27	3.76
	Forest, Deciduous	5,104	12.2	156.11	0.06	0.07	0.37	0.00	0.01
	Forest, Mixed	453	1.1	105.29	0.03	0.11	0.24	0.00	0.00
	Pasture	9,900	23.7	165.16	0.08	0.58	3.53	1.13	0.14
	Range, Brushy	2,518	6.0	180.64	0.20	0.82	0.43	0.02	0.02
	Range	17,385	41.6	219.05	0.28	1.43	0.62	0.06	0.04
	Roads	1,324	3.2	387.62	0.28	0.03	1.18	0.07	0.03
Total Area & Subbasin Averages		41,802	100.0	220.65	7.52	5.61	1.51	0.33	0.51
11070102050	Cropland, Close Grown	377	1.0	241.15	5.08	13.40	0.80	0.21	1.27
	Cropland, Row	6,375	17.0	268.18	45.57	28.90	1.11	0.16	2.51
	Forest, Deciduous	3,904	10.4	187.50	0.09	0.25	0.42	0.00	0.01
	Forest, Evergreen	354	0.9	178.38	0.11	0.36	0.37	0.00	0.01
	Forest, Mixed	847	2.3	166.71	0.09	0.30	0.36	0.00	0.01
	Pasture	12,055	32.2	105.41	0.24	1.64	0.99	0.58	0.40
	Range, Brushy	1,077	2.9	199.33	0.28	1.21	0.49	0.04	0.03
	Range	10,414	27.9	259.36	0.44	1.67	0.68	0.04	0.05
	Roads	1,528	4.1	414.34	0.28	0.03	1.22	0.07	0.03
	Wetland, Herbaceous	462	1.2	268.87	0.63	2.62	0.57	0.01	0.05
Total Area & Subbasin Averages		37,393	100.0	205.41	8.06	6.16	0.83	0.23	0.59
11070103010	Cropland, Close Grown	107	1.3	240.48	3.74	10.46	0.83	0.20	0.97
	Cropland, Row	1,746	21.4	279.28	30.92	26.40	1.27	0.14	2.07
	Forest, Deciduous	791	9.7	82.09	0.04	0.10	0.17	0.00	0.00
	Forest, Mixed	99	1.2	52.63	0.02	0.08	0.11	0.00	0.00
	Pasture	3,110	38.1	111.68	0.16	1.08	1.30	0.61	0.25
	Range	1,887	23.1	216.02	0.46	2.30	0.56	0.08	0.07
	Roads	331	4.1	423.13	0.21	0.02	1.29	0.07	0.02
	Wetland, Herbaceous	91	1.1	234.16	0.38	1.39	0.51	0.01	0.03
Total Area & Subbasin Averages		8,163	100.0	183.76	6.85	6.76	0.98	0.29	0.57
11070103020	Cropland, Close Grown	1,213	2.9	274.11	5.43	13.44	1.06	0.28	1.52
	Cropland, Row	6,432	15.3	309.93	33.96	28.73	1.48	0.23	2.53
	Urban	1,266	3.0	389.94	0.72	2.45	1.18	0.19	0.23
	Forest, Deciduous	4,174	9.9	147.34	0.10	0.27	0.30	0.00	0.01
	Forest, Mixed	684	1.6	77.54	0.05	0.15	0.15	0.00	0.00
	Pasture	16,025	38.1	124.82	0.15	1.03	1.16	0.73	0.27
	Range	8,492	20.2	222.05	0.43	2.29	0.51	0.08	0.06
	Roads	2,489	5.9	481.00	0.27	0.03	1.37	0.07	0.03
	Wetland, Woody	620	1.5	109.65	0.07	0.26	0.22	0.00	0.01
	Wetland, Herbaceous	701	1.7	235.53	0.46	1.51	0.47	0.01	0.03
Total Area & Subbasin Averages		42,096	100.0	209.14	5.55	5.77	0.96	0.35	0.55

Table 3.8-13. (Continued)

11-Digit HUC	Land Use	Area (ha)	Percent Area	Surface Runoff (mm)	Sediment Yield (t/ha)	Organic Nitrogen As N (kg/ha)	Nitrate As N (kg/ha)	Soluble Phosphorus As P (kg/ha)	Sediment-Bound Phosphorus As P (kg/ha)
11070103030	Cropland, Close Grown	359	1.5	322.59	4.85	11.91	1.34	0.30	1.31
	Cropland, Row	3,887	16.8	340.35	36.15	29.44	1.89	0.19	2.70
	Forest, Deciduous	1,536	6.6	141.01	0.12	0.31	0.32	0.00	0.01
	Pasture	11,275	48.6	140.83	0.24	1.61	1.44	0.89	0.37
	Range	4,348	18.8	273.30	0.50	2.50	0.71	0.09	0.07
	Roads	1,120	4.8	506.95	0.24	0.03	1.60	0.08	0.03
	Wetland, Woody	248	1.1	116.67	0.08	0.27	0.26	0.01	0.01
	Wetland, Herbaceous	408	1.8	335.38	0.58	2.45	0.76	0.01	0.05
Total Area & Subbasin Averages		23,180	100.0	222.81	6.38	6.44	1.29	0.49	0.67
11070103031	Cropland, Row	1,270	3.1	396.96	41.61	20.83	1.19	0.09	1.68
	Forest, Deciduous	3,085	7.5	214.24	0.39	0.62	0.51	0.00	0.03
	Pasture	15,507	37.8	199.62	0.57	2.28	2.62	1.29	0.65
	Range	19,162	46.7	298.29	0.60	1.80	0.82	0.07	0.06
	Roads	1,428	3.5	478.67	0.22	0.03	1.45	0.08	0.02
	Wetland, Woody	573	1.4	184.84	0.27	0.46	0.43	0.00	0.02
Total Area & Subbasin Averages		41,026	100.0	262.42	1.82	2.40	1.50	0.53	0.33
11070103040	Cropland, Close Grown	963	3.0	388.34	4.01	8.04	2.05	0.38	1.11
	Cropland, Row	5,162	16.3	379.09	40.29	29.28	2.60	0.24	2.84
	Urban	284	0.9	313.33	0.59	1.63	1.06	0.21	0.11
	Forest, Deciduous	2,907	9.2	144.08	0.12	0.28	0.31	0.00	0.01
	Forest, Mixed	278	0.9	119.35	0.09	0.24	0.25	0.00	0.01
	Pasture	13,754	43.5	144.79	0.24	1.68	1.72	0.96	0.40
	Range, Brushy	152	0.5	197.13	0.38	1.41	0.45	0.04	0.04
	Range	5,941	18.8	305.59	0.42	1.69	0.81	0.09	0.05
	Roads	1,308	4.1	500.02	0.24	0.03	1.52	0.08	0.03
	Wetland, Woody	307	1.0	140.75	0.07	0.24	0.31	0.01	0.01
	Wetland, Herbaceous	576	1.8	221.21	0.45	1.40	0.48	0.01	0.04
Total Area & Subbasin Averages		31,632	100.0	238.15	6.92	6.15	1.50	0.49	0.69
11070103041	Cropland, Row	2,882	6.6	383.42	41.49	34.23	1.82	0.35	4.40
	Forest, Deciduous	4,638	10.6	207.02	0.30	0.60	0.50	0.01	0.02
	Pasture	13,694	31.3	200.48	0.41	2.18	2.23	1.20	0.53
	Range	20,496	46.9	317.59	0.41	1.57	0.94	0.09	0.05
	Roads	1,301	3.0	489.87	0.26	0.03	1.51	0.08	0.03
	Wetland, Woody	719	1.6	171.27	0.22	0.45	0.41	0.01	0.02
Total Area & Subbasin Averages		43,730	100.0	276.25	3.10	3.75	1.37	0.44	0.49

Table 3.8-13. (Continued)

11-Digit HUC	Land Use	Area (ha)	Percent Area	Surface Runoff (mm)	Sediment Yield (t/ha)	Organic Nitrogen As N (kg/ha)	Nitrate As N (kg/ha)	Soluble Phosphorus As P (kg/ha)	Sediment-Bound Phosphorus As P (kg/ha)
11070103050	Cropland, Close Grown	1,260	3.3	483.65	8.22	13.65	2.71	0.42	1.88
	Cropland, Row	6,709	17.8	513.54	52.36	32.51	4.04	0.29	3.07
	Forest, Deciduous	1,368	3.6	216.43	0.13	0.40	0.49	0.01	0.01
	Pasture	20,985	55.7	280.93	0.39	2.56	4.98	1.77	0.59
	Range	4,741	12.6	348.25	0.55	2.27	0.93	0.08	0.06
	Roads	1,461	3.9	506.54	0.21	0.02	1.54	0.08	0.02
	Wetland, Woody	532	1.4	159.31	0.09	0.32	0.35	0.01	0.01
	Wetland, Herbaceous	639	1.7	395.52	0.62	2.35	0.90	0.02	0.05
Total Area & Subbasin Averages		37,694	100.0	344.20	9.90	8.01	3.80	1.07	0.95
11070103051	Forest, Deciduous	12,618	14.1	242.17	0.01	0.02	0.58	0.02	0.00
	Pasture	40,742	45.5	171.16	0.28	1.42	1.96	1.15	0.37
	Range, Brushy	944	1.1	282.14	0.05	0.10	0.73	0.06	0.01
	Range	26,569	29.7	282.69	0.51	1.89	0.83	0.09	0.06
	Roads	3,951	4.4	478.58	0.22	0.03	1.51	0.08	0.03
	Wetland, Woody	2,988	3.3	142.65	0.17	0.39	0.33	0.01	0.01
	Wetland, Herbaceous	1,663	1.9	359.09	0.53	1.67	0.86	0.02	0.04
Total Area & Subbasin Averages		89,475	100.0	231.58	0.31	1.26	1.32	0.56	0.19
11070103065	Cropland, Close Grown	346	1.2	457.47	7.40	13.71	3.11	0.41	1.80
	Cropland, Row	4,054	13.9	314.43	28.20	28.28	1.87	0.21	2.62
	Forest, Deciduous	3,026	10.4	102.01	0.04	0.11	0.22	0.00	0.00
	Pasture	11,981	41.2	126.29	0.13	1.01	1.31	0.87	0.26
	Range, Brushy	383	1.3	140.01	0.17	0.75	0.33	0.05	0.02
	Range	6,911	23.8	245.90	0.35	1.78	0.63	0.09	0.05
	Roads	1,560	5.4	480.46	0.20	0.02	1.48	0.08	0.02
	Wetland, Woody	307	1.1	94.71	0.04	0.18	0.20	0.00	0.00
	Wetland, Herbaceous	514	1.8	242.86	0.35	1.28	0.53	0.01	0.03
Total Area & Subbasin Averages		29,083	100.0	203.27	4.18	4.99	1.11	0.42	0.51
11070103073	Cropland, Row	3,681	8.6	358.23	36.71	31.76	1.77	0.34	3.93
	Forest, Deciduous	3,675	8.6	190.06	0.18	0.16	0.44	0.01	0.01
	Pasture	19,106	44.6	210.35	0.34	1.47	2.53	1.19	0.33
	Range	14,347	33.5	313.52	0.42	1.17	0.87	0.06	0.04
	Roads	1,584	3.7	477.66	0.18	0.02	1.43	0.08	0.02
	Wetland, Woody	438	1.0	160.63	0.12	0.33	0.36	0.00	0.01
Total Area & Subbasin Averages		42,831	100.0	265.25	3.47	3.79	1.67	0.58	0.50

Table 3.8-13. (Continued)

11-Digit HUC	Land Use	Area (ha)	Percent Area	Surface Runoff (mm)	Sediment Yield (t/ha)	Organic Nitrogen As N (kg/ha)	Nitrate As N (kg/ha)	Soluble Phosphorus As P (kg/ha)	Sediment-Bound Phosphorus As P (kg/ha)
11070104010	Cropland, Row	5,308	9.4	228.32	40.80	29.59	0.86	0.21	3.58
	Forest, Deciduous	1,496	2.6	83.12	0.07	0.26	0.18	0.00	0.01
	Pasture	12,682	22.4	137.08	0.30	2.10	1.96	0.90	0.52
	Range, Brushy	3,192	5.6	160.33	0.36	1.79	0.41	0.06	0.05
	Range	31,872	56.2	194.25	0.41	1.88	0.53	0.06	0.05
	Roads	1,527	2.7	413.27	0.30	0.03	1.22	0.07	0.03
	Wetland, Herbaceous	652	1.1	228.98	0.55	2.48	0.49	0.01	0.04
Total Area & Subbasin Averages		56,731	100.0	186.11	4.15	4.43	0.88	0.26	0.49
11070104020	Cropland, Row	4,058	7.8	270.37	33.83	28.01	1.21	0.30	3.55
	Forest, Deciduous	6,969	13.4	173.57	0.06	0.11	0.41	0.00	0.01
	Forest, Mixed	581	1.1	138.33	0.05	0.15	0.32	0.00	0.01
	Pasture	13,863	26.7	188.52	0.29	1.95	3.06	1.26	0.55
	Range, Brushy	4,050	7.8	195.03	0.20	0.84	0.49	0.05	0.03
	Range	20,851	40.2	236.53	0.35	1.48	0.63	0.05	0.04
	Roads	1,499	2.9	439.06	0.32	0.04	1.32	0.07	0.03
Total Area & Subbasin Averages		51,871	100.0	219.40	2.90	3.39	1.30	0.39	0.44
11070104030	Cropland, Close Grown	429	2.7	401.46	8.81	13.89	2.02	0.29	1.68
	Cropland, Row	2,738	17.4	436.31	72.66	31.91	3.26	0.18	2.83
	Forest, Deciduous	649	4.1	159.39	0.04	0.10	0.38	0.00	0.00
	Pasture	5,606	35.6	108.33	0.23	1.63	1.14	0.69	0.43
	Range, Brushy	323	2.1	128.10	0.24	0.92	0.29	0.02	0.02
	Range	5,453	34.6	205.51	0.47	2.37	0.53	0.07	0.06
	Roads	542	3.4	439.02	0.23	0.03	1.36	0.07	0.03
Total Area & Subbasin Averages		15,740	100.0	220.94	13.14	7.36	1.28	0.31	0.71
11070104040	Cropland, Close Grown	293	1.8	438.82	9.47	19.07	2.44	0.39	2.13
	Cropland, Row	2,006	12.1	472.43	72.73	38.54	3.33	0.20	3.12
	Forest, Deciduous	1,468	8.8	261.51	0.26	0.69	0.61	0.01	0.02
	Forest, Evergreen	277	1.7	211.46	0.14	0.41	0.48	0.00	0.01
	Forest, Mixed	464	2.8	222.29	0.18	0.53	0.51	0.01	0.02
	Pasture	5,042	30.3	124.76	0.29	2.06	1.05	0.77	0.51
	Range, Brushy	542	3.3	285.75	0.44	1.79	0.74	0.04	0.05
	Range	5,518	33.2	356.10	0.56	2.79	0.98	0.08	0.08
	Roads	588	3.5	485.55	0.31	0.04	1.51	0.08	0.04
	Wetland, Woody	186	1.1	213.20	0.16	0.49	0.50	0.01	0.02
	Wetland, Herbaceous	256	1.5	335.52	0.64	2.63	0.77	0.01	0.06
Total Area & Subbasin Averages		16,638	100.0	287.37	9.27	6.72	1.26	0.30	0.60

Table 3.8-13. (Continued)

11-Digit HUC	Land Use	Area (ha)	Percent Area	Surface Runoff (mm)	Sediment Yield (t/ha)	Organic Nitrogen As N (kg/ha)	Nitrate As N (kg/ha)	Soluble Phosphorus As P (kg/ha)	Sediment- Bound Phosphorus As P (kg/ha)
11070104041	Cropland, Close Grown	281	0.7	442.20	9.93	15.48	3.08	0.38	2.14
	Cropland, Row	4,547	11.5	364.00	64.74	37.62	2.52	0.22	4.05
	Forest, Deciduous	7,290	18.4	155.47	0.05	0.07	0.37	0.00	0.01
	Forest, Mixed	620	1.6	132.91	0.06	0.16	0.31	0.00	0.01
	Pasture	11,931	30.1	196.79	0.45	3.36	3.75	1.53	0.96
	Range, Brushy	1,614	4.1	190.11	0.32	1.32	0.49	0.05	0.04
	Range	11,329	28.6	269.10	0.56	2.48	0.73	0.06	0.07
	Roads	1,373	3.5	459.35	0.28	0.03	1.46	0.08	0.03
	Wetland, Woody	479	1.2	242.58	0.19	0.56	0.59	0.01	0.02
	Wetland, Herbaceous	207	0.5	260.18	0.52	2.67	0.59	0.02	0.05
Total Area & Subbasin Averages		39,670	100.0	239.45	7.82	6.23	1.80	0.51	0.79

Table 3.8-14. Estimated average annual sediment and nutrient export rates in the Oologah Lake watershed by land use.

Land Use	Area (ha)	Percent Area	Surface Runoff (mm/yr)	Sediment Yield (t/ha/yr)	Organic Nitrogen (kg/ha/yr)	Nitrate (kg/ha/yr)	Soluble Phosphorus (kg/ha/yr)	Sediment-Bound Phosphorus (kg/ha/yr)	Total Nitrogen (kg/ha/yr)	Total Phosphorus (kg/ha/yr)
Crop, Close Grown	6,347	0.58	371.10	6.43	12.81	1.88	0.33	1.54	14.70	1.87
Crop, Row	110,636	10.09	348.61	47.49	32.81	1.95	0.22	3.10	34.77	3.32
Urban	1,550	0.14	375.90	0.69	2.30	1.16	0.19	0.21	3.46	0.40
Forest, Deciduous	85,548	7.81	172.50	0.10	0.20	0.40	0.01	0.01	0.60	0.01
Forest, Evergreen	631	0.06	192.91	0.12	0.39	0.42	0.00	0.01	0.81	0.02
Forest, Mixed	4,728	0.43	134.83	0.07	0.23	0.30	0.00	0.01	0.53	0.01
Pasture	341,086	31.12	166.20	0.39	1.99	2.17	1.03	0.46	4.16	1.49
Range, Brushy	30,070	2.74	179.92	0.34	1.55	0.46	0.05	0.04	2.01	0.09
Range	457,855	41.77	242.21	0.41	1.70	0.65	0.05	0.05	2.35	0.10
Roads	39,970	3.65	444.99	0.25	0.03	1.37	0.07	0.03	1.40	0.10
Wetland, Woody	8,402	0.77	146.70	0.14	0.36	0.34	0.01	0.01	0.70	0.02
Wetland, Herbaceous	9,237	0.84	280.34	0.55	2.23	0.63	0.01	0.04	2.86	0.06
Basin Total & Averages	1,096,061	100.00	229.57	5.16	4.80	1.26	0.37	0.49	6.06	0.86

Table 3.8-15. Estimated average annual sediment and nutrient loading in the Oologah Lake watershed by land use.

Land Use	Area (ha)	Percent Area	Sediment Yield (t/yr)	Organic Nitrogen (kg/yr)	Nitrate (kg/yr)	Soluble Phosphorus (kg/yr)	Sediment- Bound Phosphorus (kg/yr)	Total Nitrogen (kg/yr)	Total Phosphorus (kg/yr)
Crop, Close Grown	6,347	0.58	40,799	81,331	11,945	2,093	9,757	93,276	11,850
Crop, Row	110,636	10.09	5,253,765	3,630,306	216,244	24,726	342,867	3,846,550	367,593
Urban	1,550	0.14	1,076	3,569	1,800	301	320	5,369	621
Forest, Deciduous	85,548	7.81	8,412	17,390	34,282	519	760	51,672	1,279
Forest, Evergreen	631	0.06	78	243	265	3	8	508	10
Forest, Mixed	4,728	0.43	354	1,090	1,405	17	36	2,495	53
Pasture	341,086	31.12	132,722	677,393	741,609	351,402	158,253	1,419,002	509,655
Range, Brushy	30,070	2.74	10,257	46,461	13,890	1,512	1,336	60,350	2,848
Range	457,855	41.77	187,825	778,010	296,858	23,880	21,112	1,074,869	44,992
Roads	39,970	3.65	10,140	1,202	54,586	2,957	1,135	55,787	4,092
Wetland, Woody	8,402	0.77	1,208	3,032	2,840	43	103	5,871	146
Wetland, Herbaceous	9,237	0.84	5,060	20,564	5,839	124	409	26,403	533
Basin Totals	1,096,061	100.00	5,651,697	5,260,591	1,381,561	407,577	536,094	6,642,153	943,671

Table 3.8-16. Comparison of estimated annual averages and quartile ranges of sediment and nutrients delivered to Oologah Lake.

	SWAT Modeled Estimates			Regression Estimates (2000 – 2001)		
	Sediment (Metric tons)	Total Nitrogen (kg)	Total Phosphorus (kg)	Total Suspended Solids (Metric tons/yr)	Total Nitrogen (kg/yr)	Total Phosphorus (kg/yr)
Mean	834,100	5,688,000	501,500	489,330	4,142,800	616,900
St. Dev.	549,900	2,338,100	256,100	---	---	---
25 th Percentile	520,600	4,326,900	316,700	3,930	108,000	4,380
Median	680,000	5,559,500	467,800	15,439	744,600	40,150
75 th Percentile	1,056,800	6,786,000	678,900	150,140	3,339,400	295,000

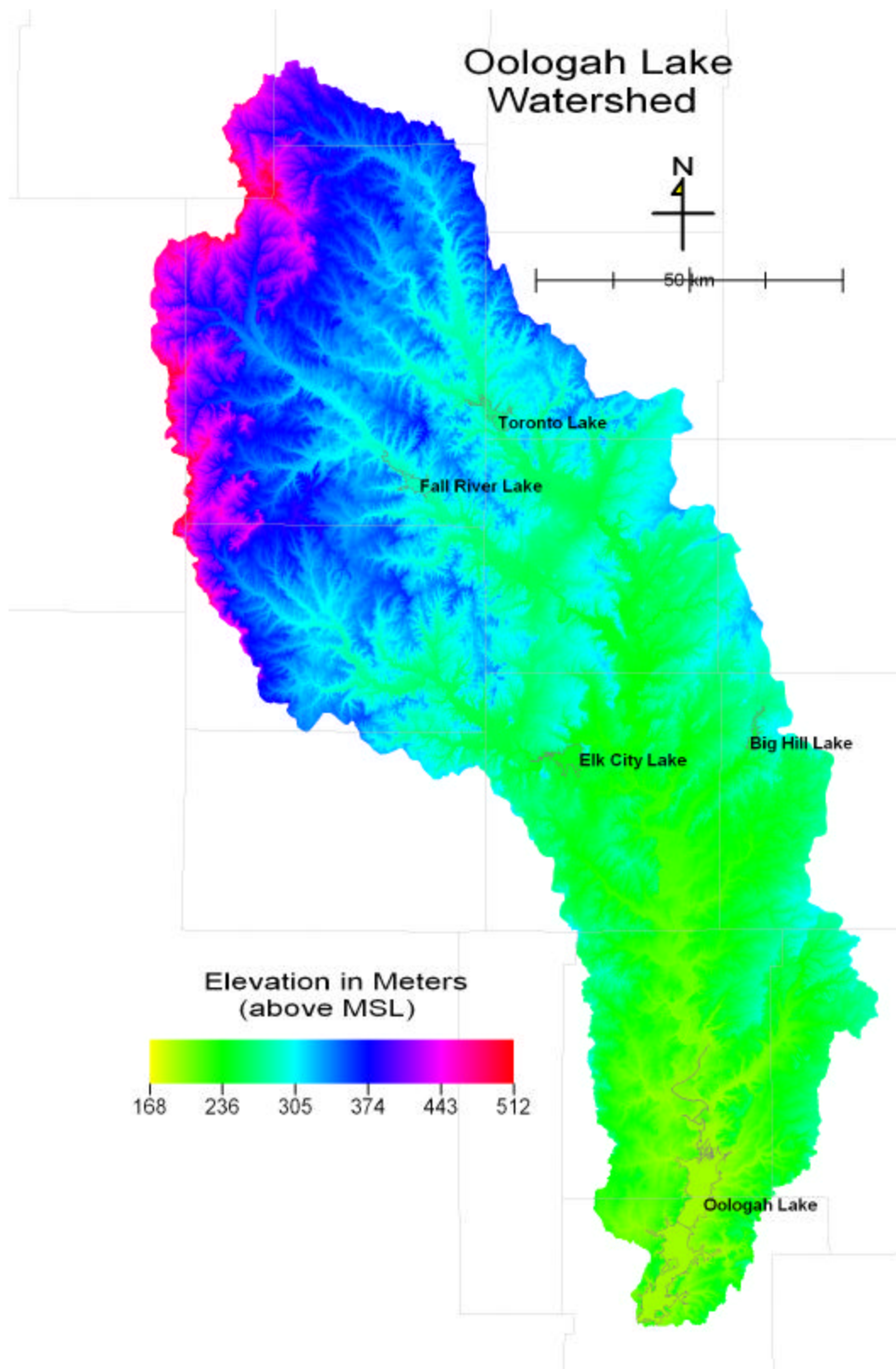


Figure 3.8-1
Elevation in meters above sea level for the Oologah Lake watershed
derived from USGS 7.5-minute DEM quadrangles.

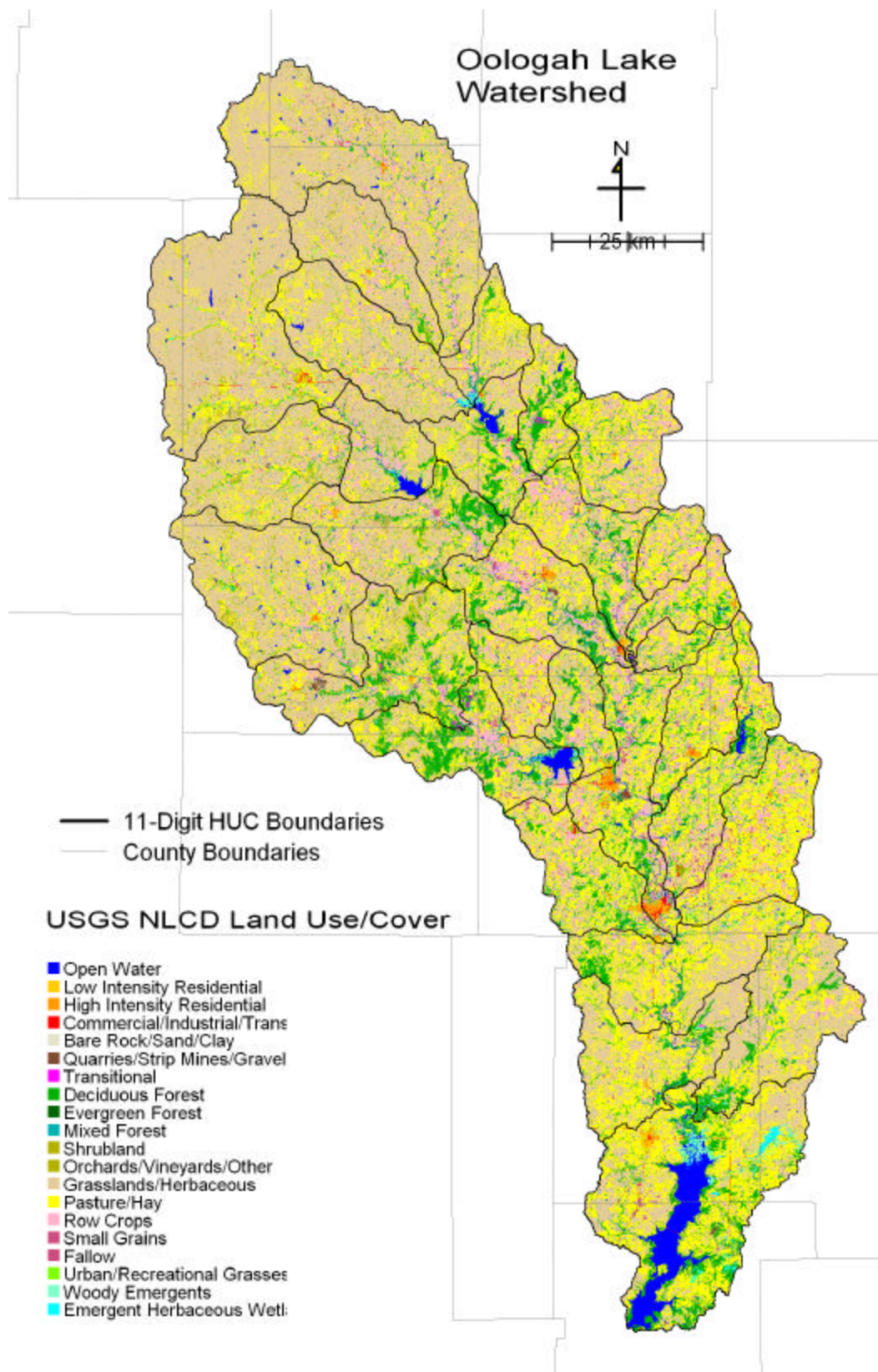


Figure 3.8-2
Land use/cover in the Oologah Lake watershed derived from USGS NLCD data for Kansas and Oklahoma.

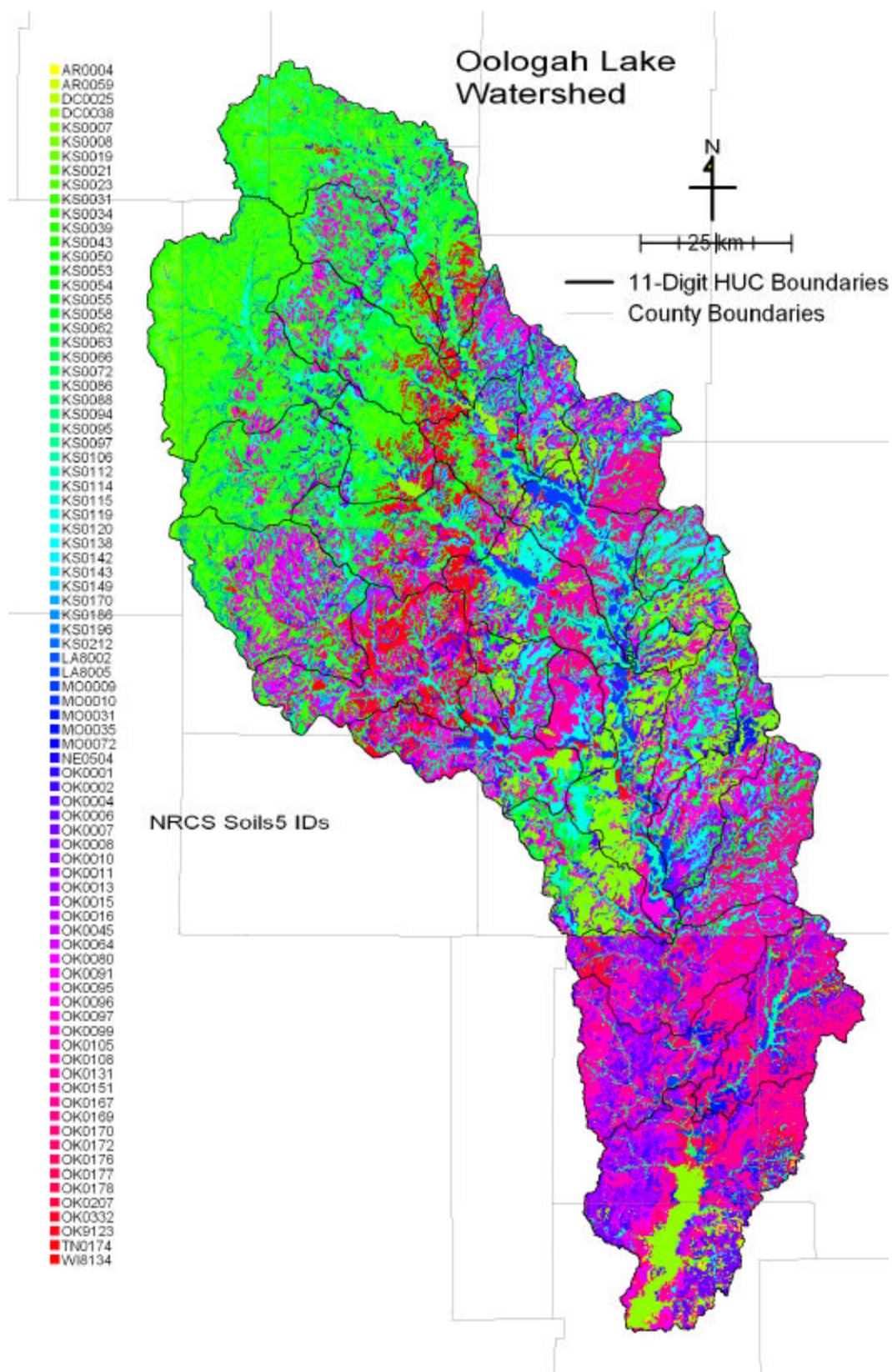


Figure 3.8-3
Oologah Lake watershed soils identified by Soils5 IDs.

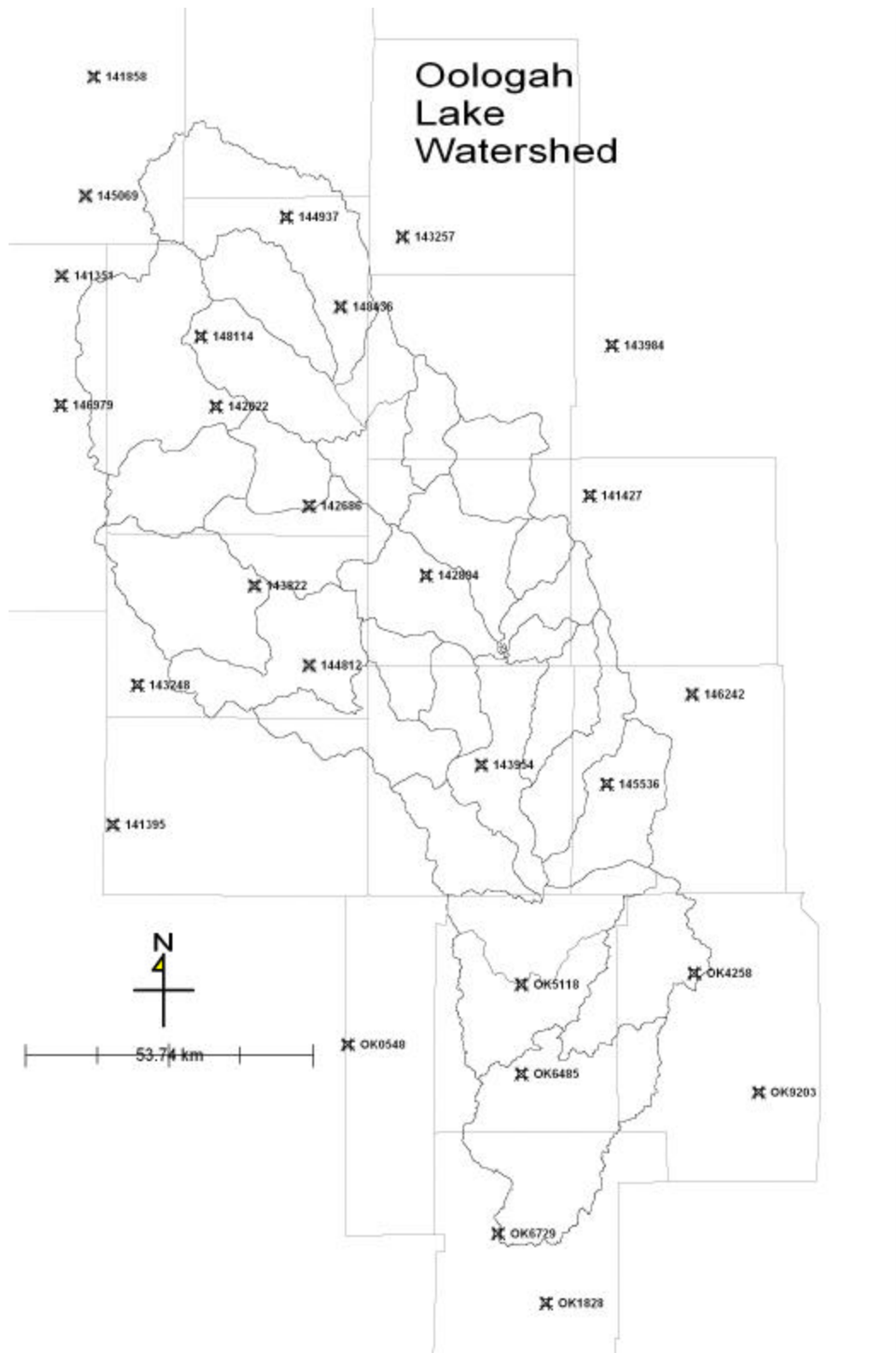


Figure 3.8-4
Weather station locations and identification numbers in and around the Oologah Lake watershed.

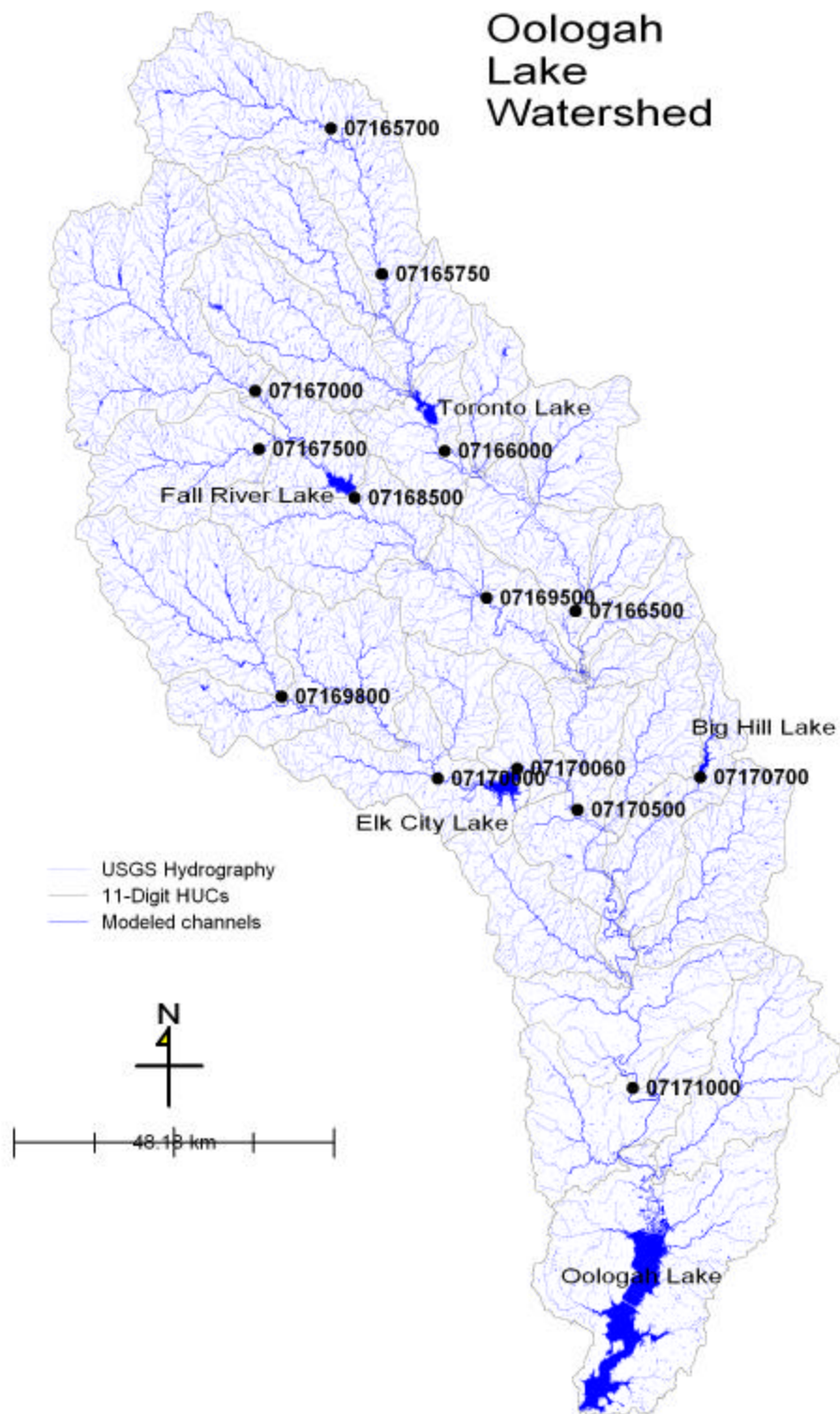


Figure 3.8-5
USGS hydrography, USGS gaging station locations with historical mean daily discharge data, and USACE reservoirs in the Oologah Lake watershed.

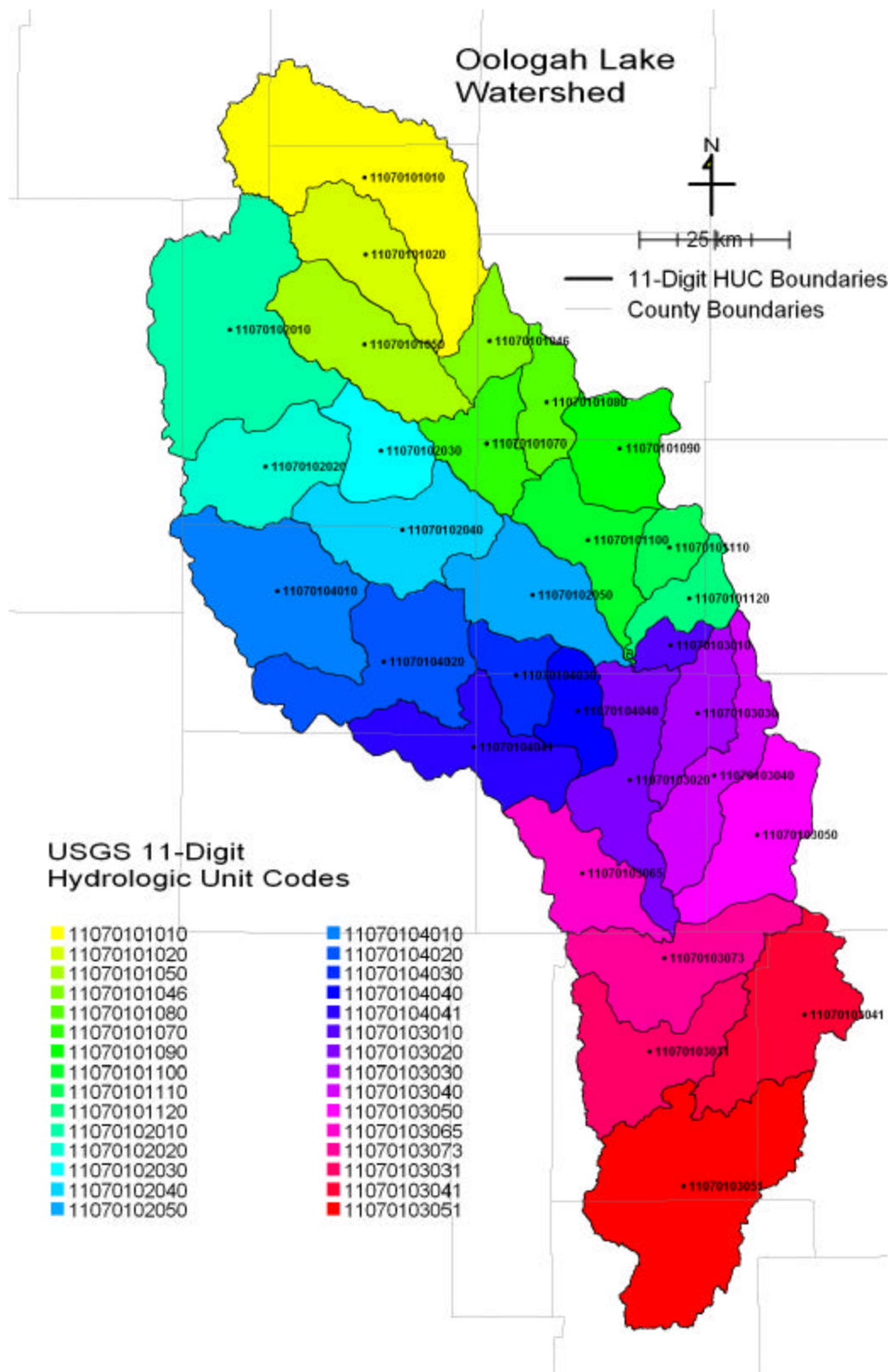


Figure 3.8-6
 Subbasins in the Oologah Lake watershed identified by 11-digit HUCs.

Gage 07165700

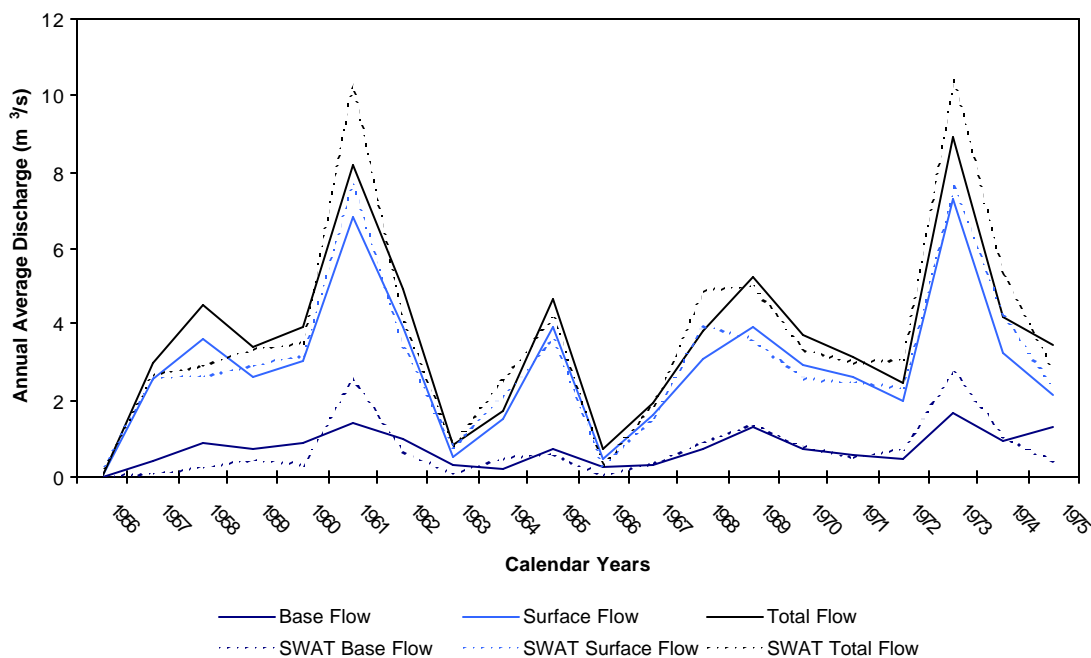


Figure 3.8-7
Comparison of measured and simulated base, surface, and total discharge at USGS 07165700.

USGS 07171000

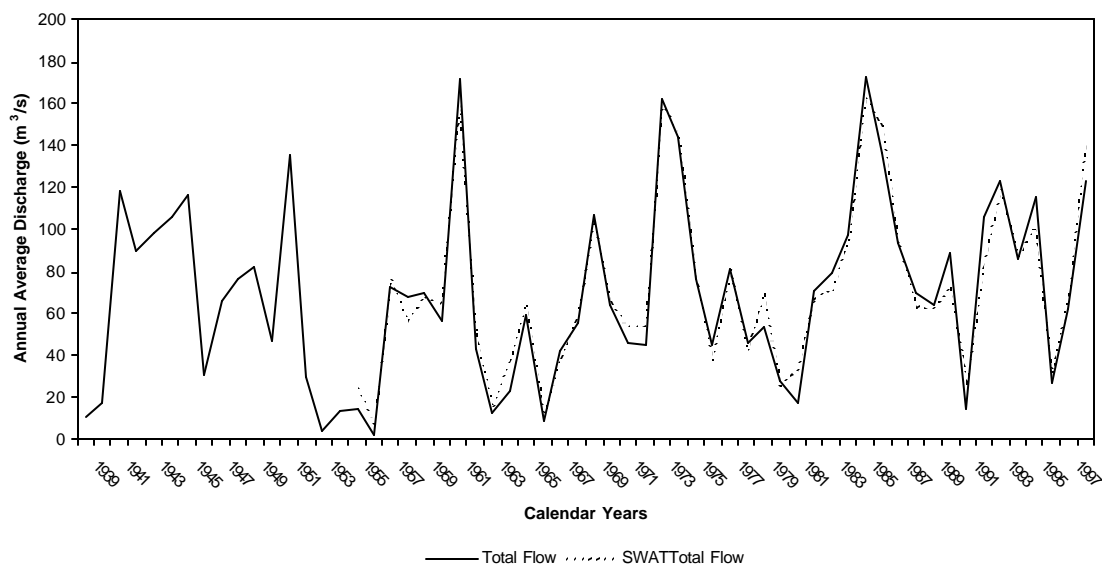


Figure 3.8-8
Comparison of measured and simulated annual mean discharge at USGS 07171000 (Verdigris River at Lenapah).

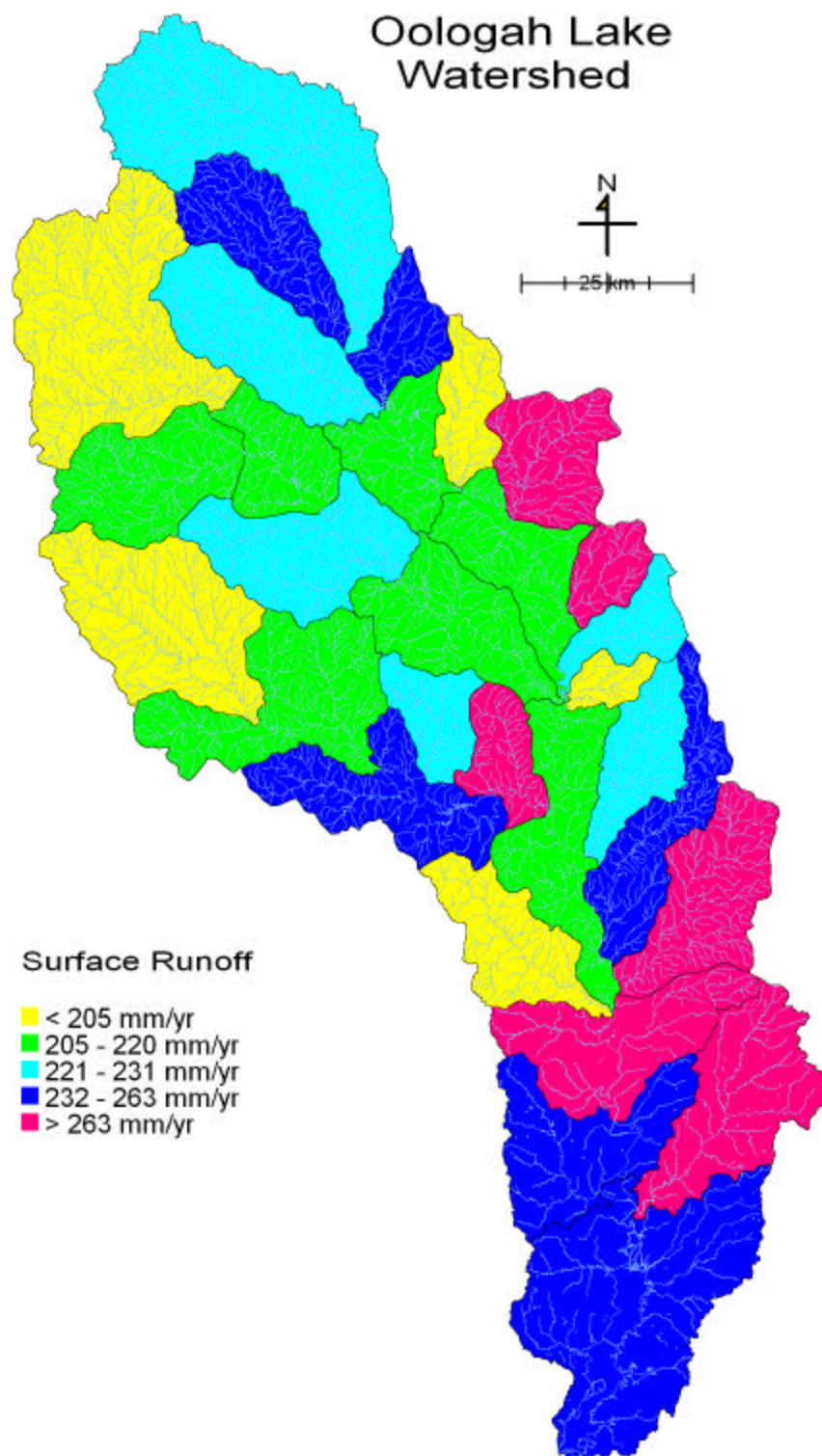


Figure 3.8-9
Estimated annual average surface runoff (mm/yr) in the Oologah Lake watershed by 11-digit HUC subbasin.

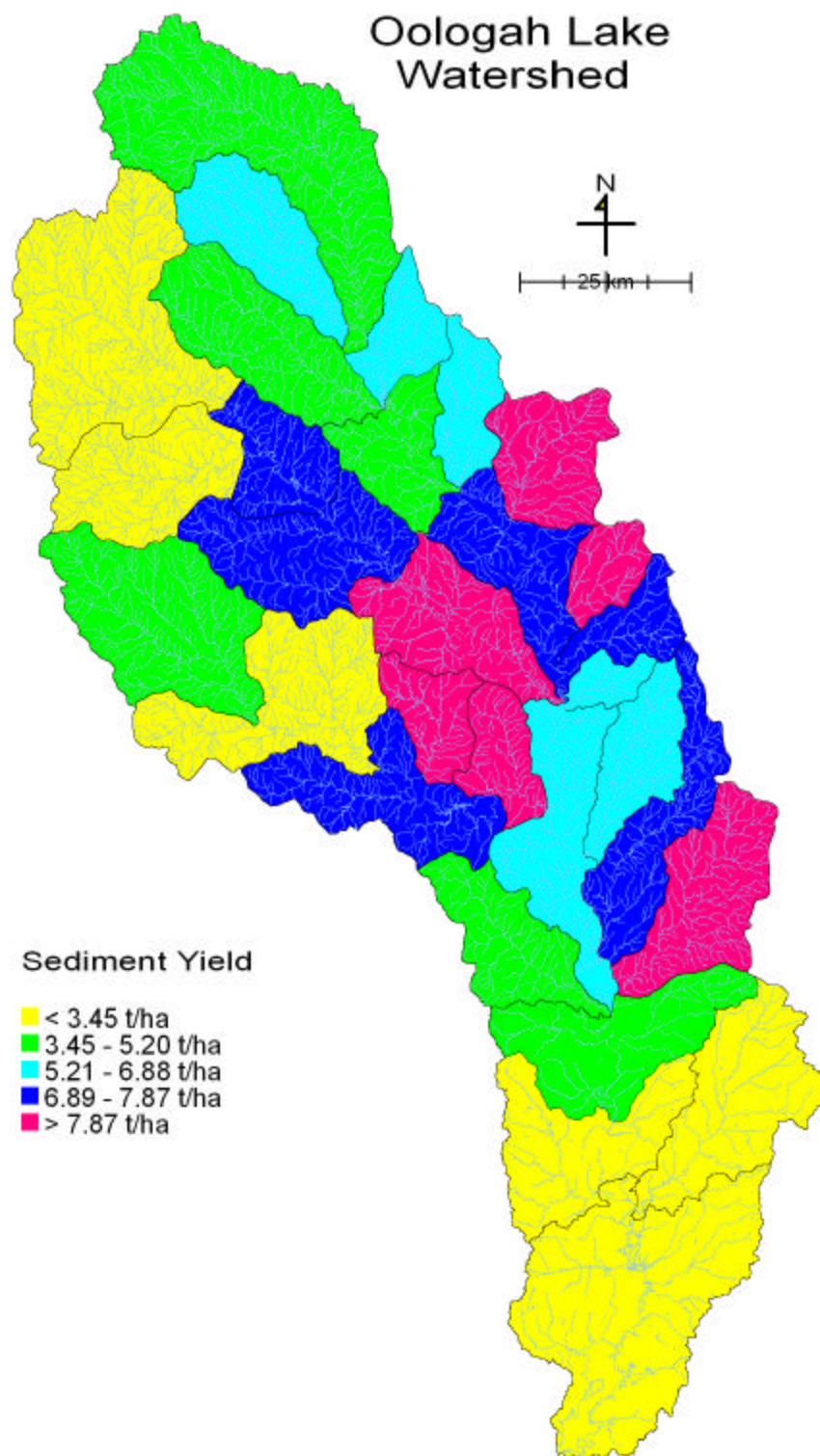


Figure 3.8-10
Estimated annual average sediment export (t/ha) in the Oologah Lake watershed by 11-digit HUC subbasin.

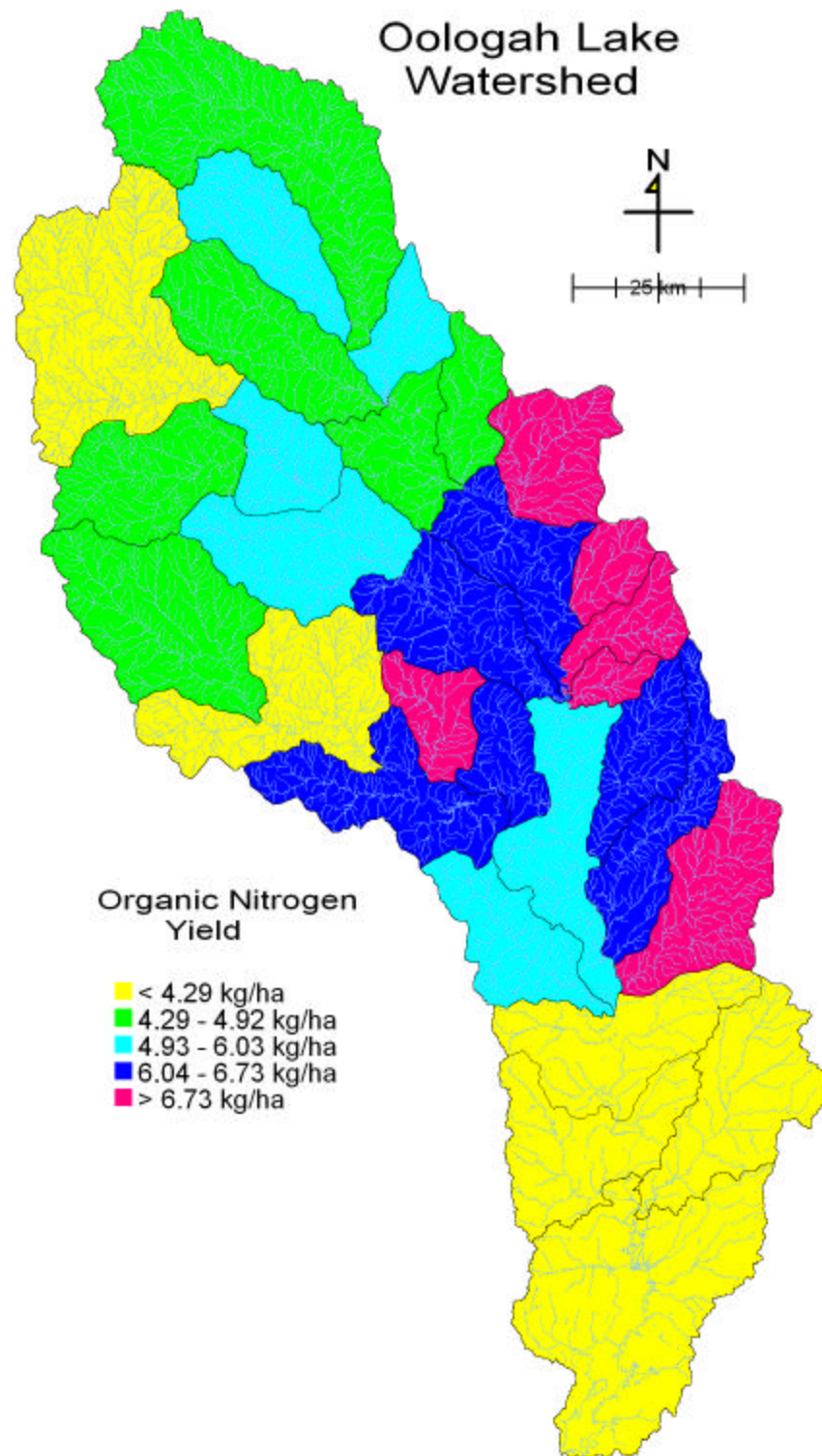


Figure 3.8-11
Estimated annual average organic nitrogen (kg/ha as N) export in the
Oologah Lake watershed by 11-digit HUC subbasin.

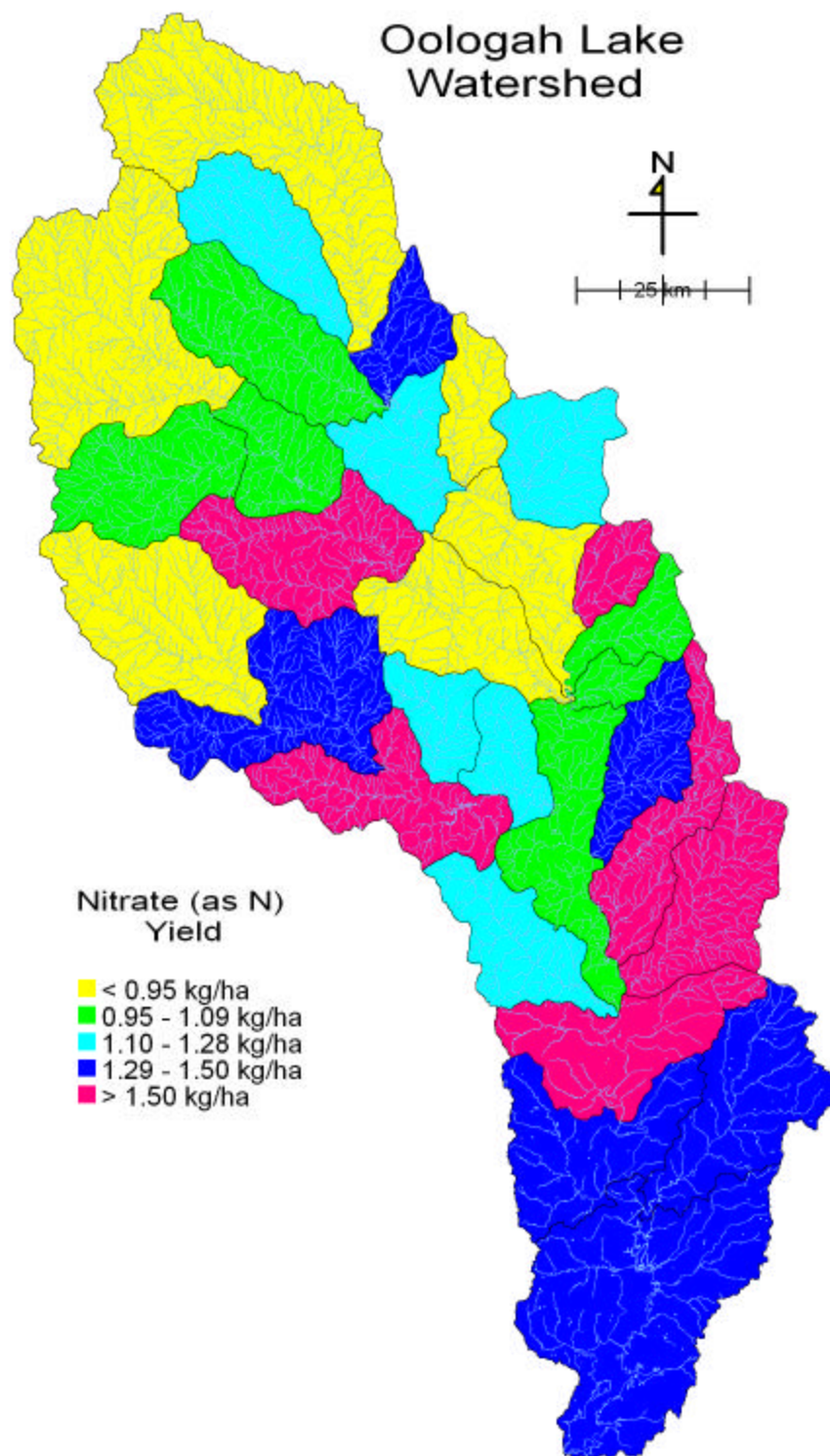


Figure 3.8-12
Estimated annual average nitrate (kg/ha as N) export in the Oologah Lake watershed
by 11-digit HUC subbasin.

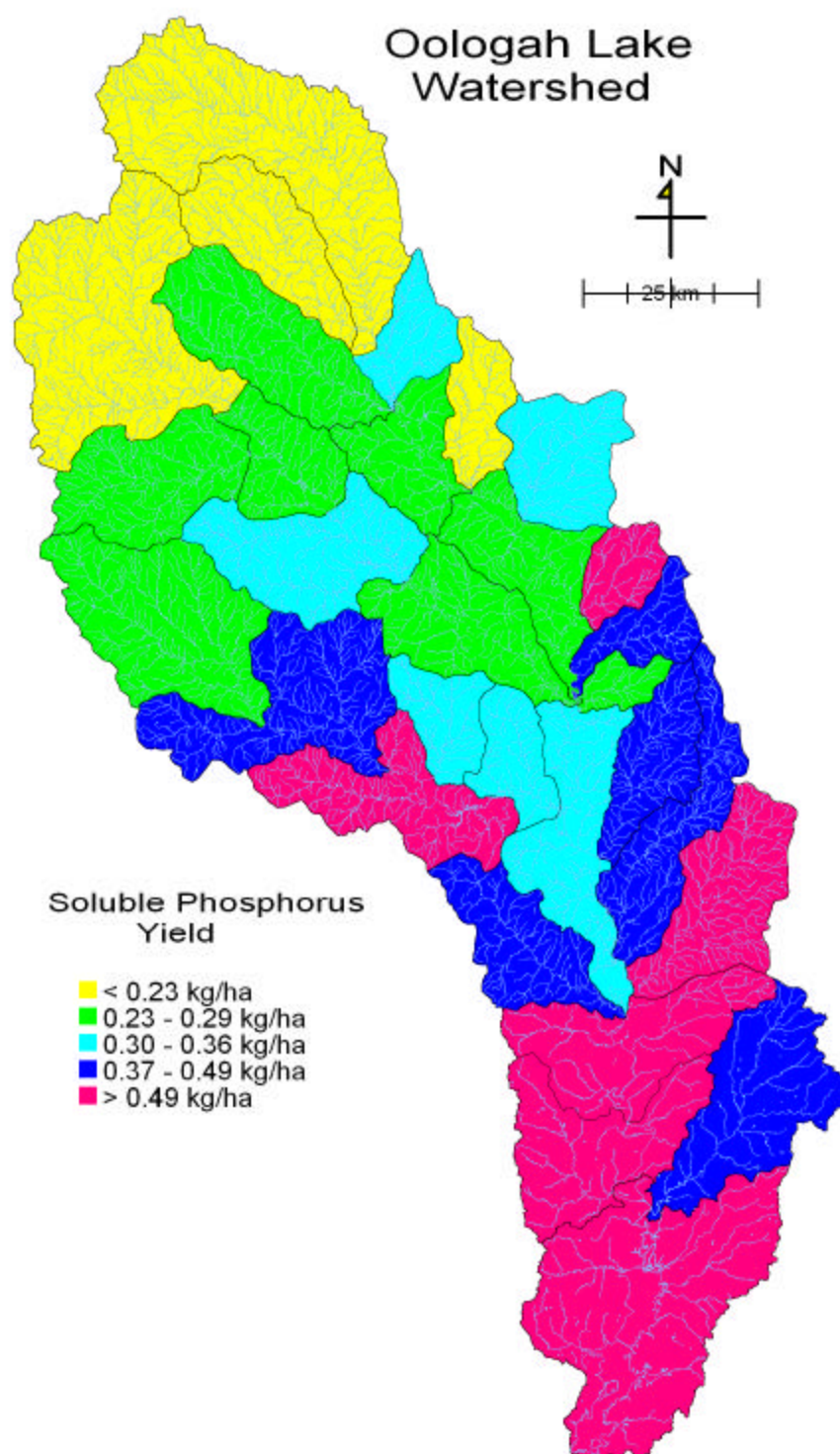


Figure 3.8-13
Estimated annual average soluble phosphorus (kg/ha as P) export in the Oologah Lake watershed
by 11-digit HUC subbasin.

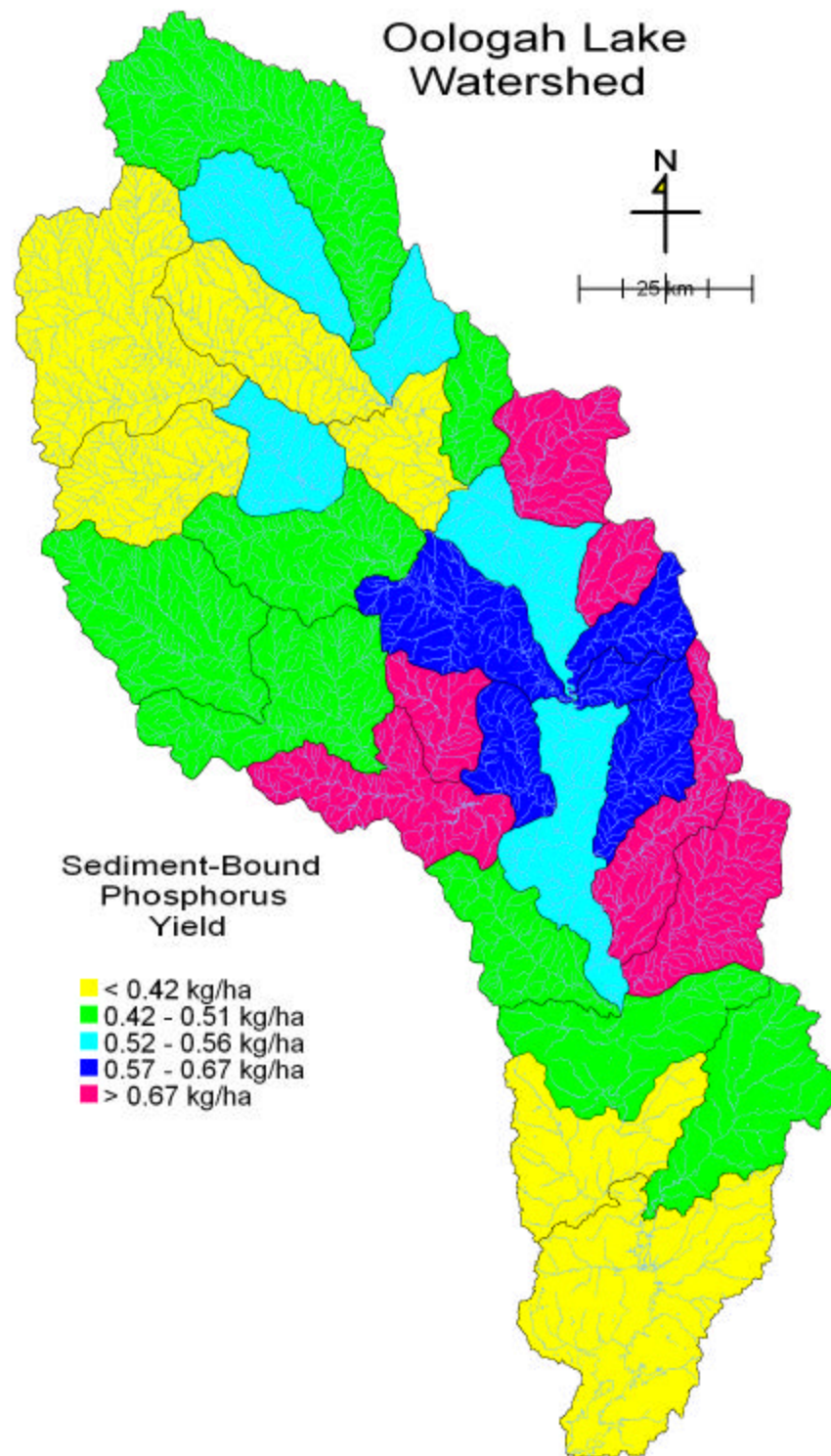


Figure 3.8-14
Estimated annual average sediment-bound phosphorus (kg/ha as P) in the Oologah Lake watershed by 11-digit HUC subbasin.

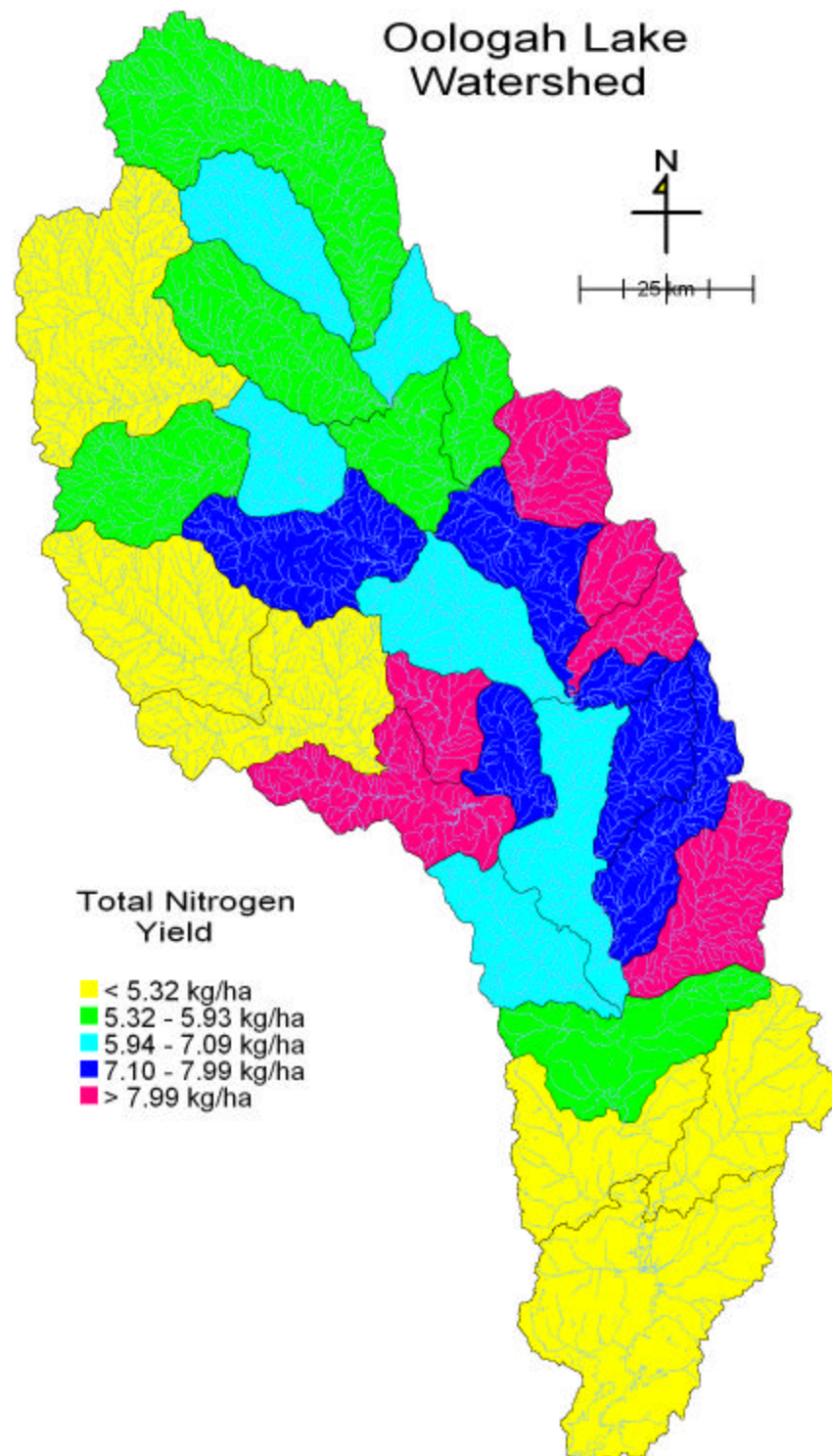


Figure 3.8-15
Estimated annual average total nitrogen (kg/ha as N) export in the Oologah Lake watershed
by 11-digit HUC subbasin.

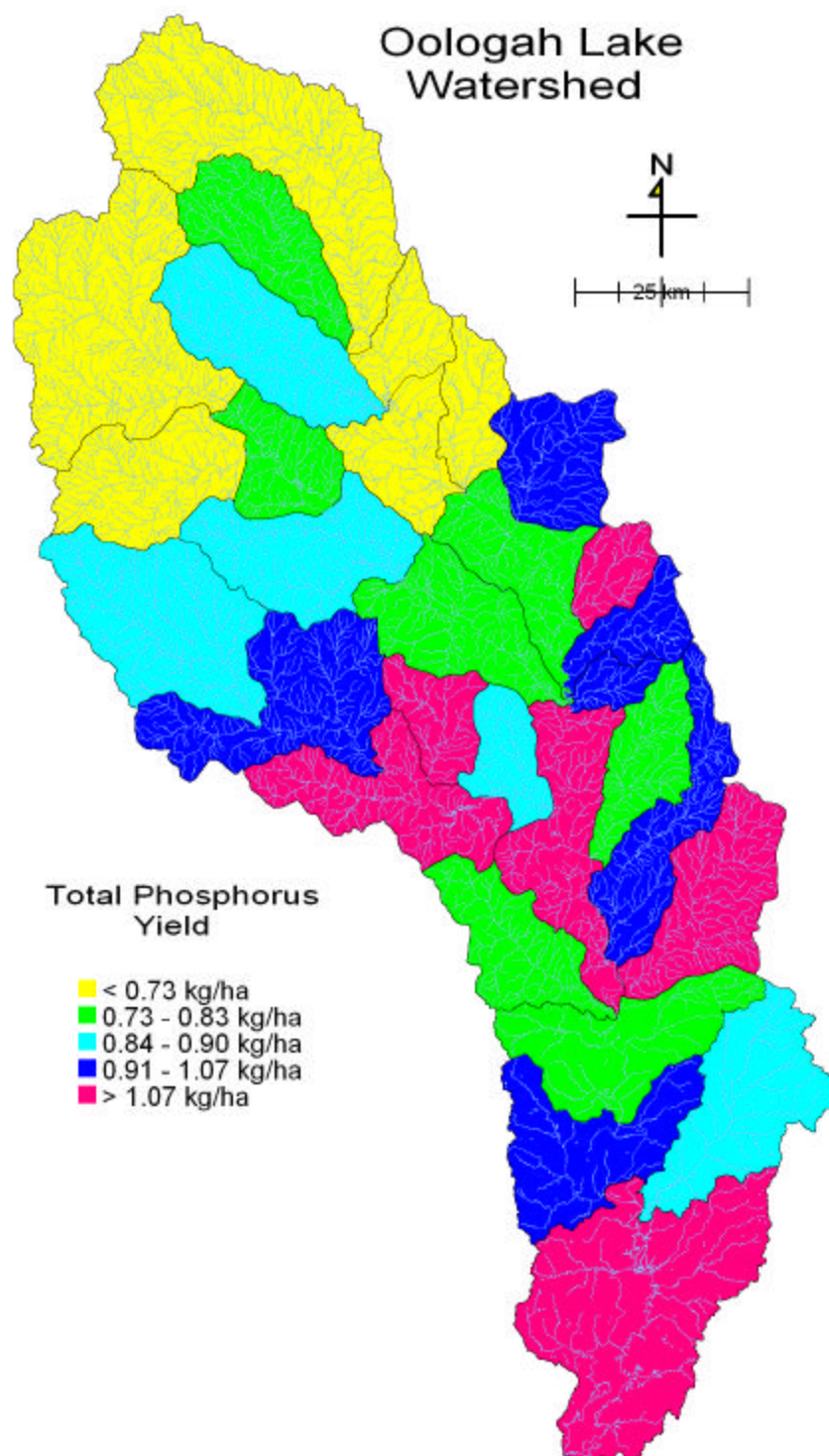


Figure 3.8-16
Estimated annual average total phosphorus (kg/ha as P) export in the Oologah Lake watershed
by 11-digit HUC subbasin.

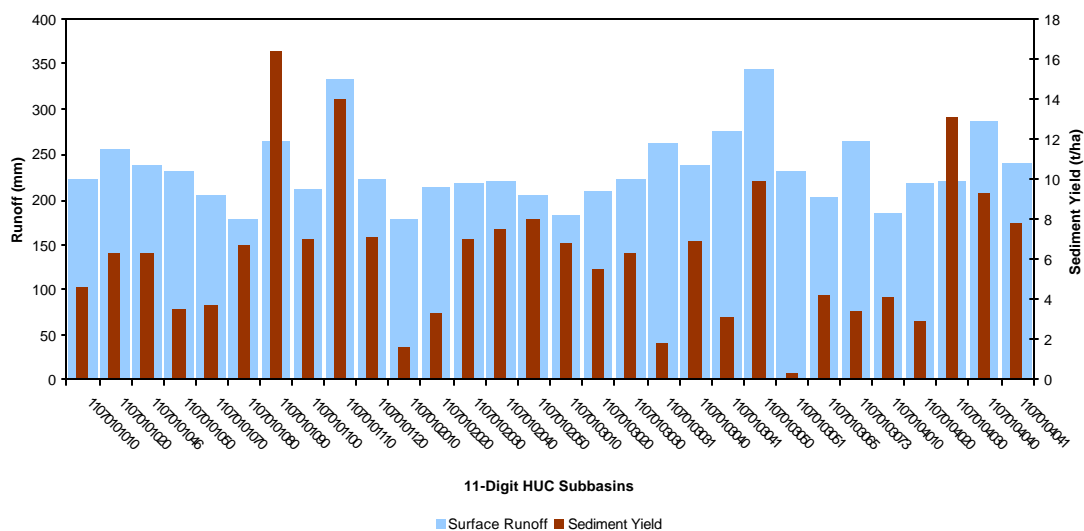


Figure 3.8-17
Comparison of estimated average annual runoff and sediment export by 11-digit HUC subbasin.

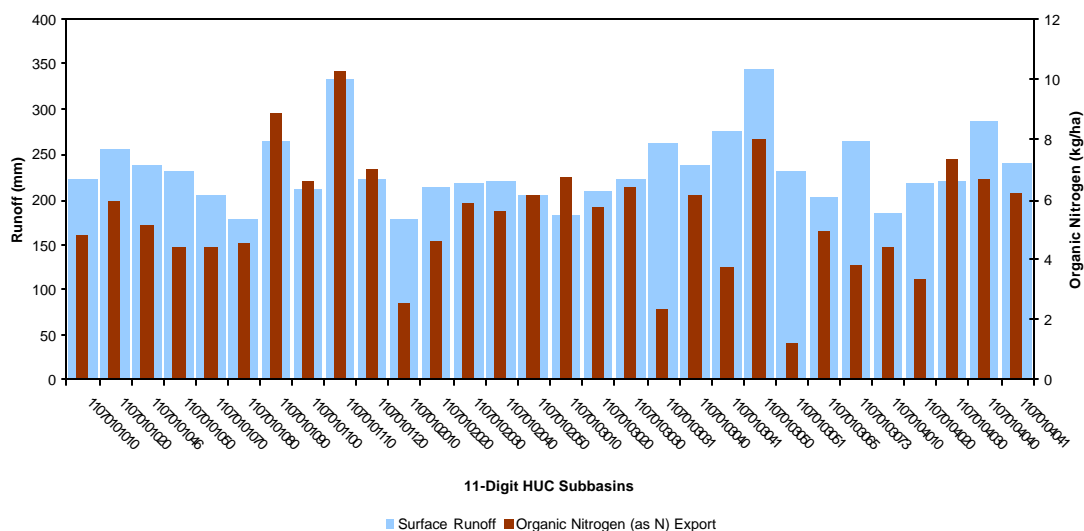


Figure 3.8-18
Comparison of estimated average annual runoff and organic nitrogen export by 11-digit HUC subbasin.

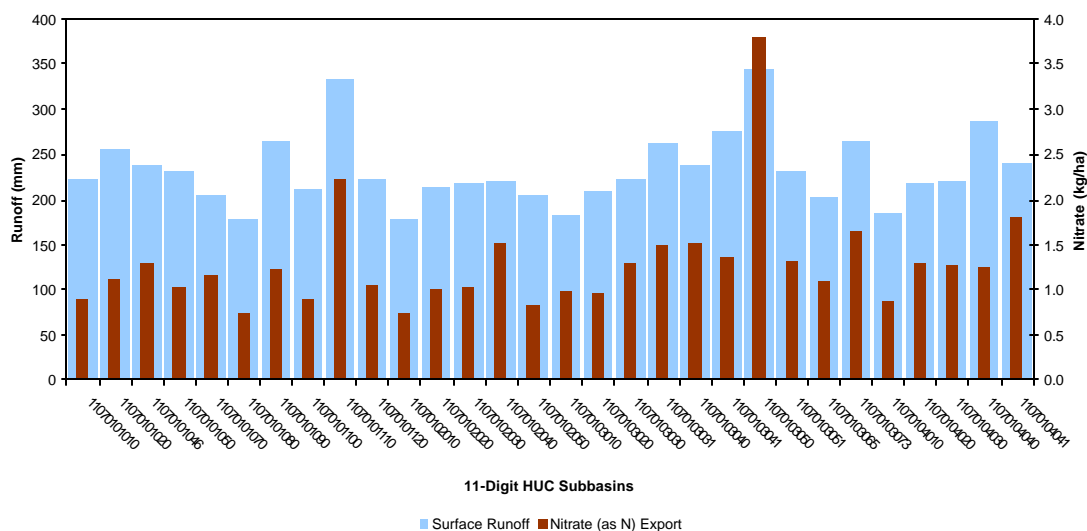


Figure 3.8-19
Comparison of estimated average annual runoff and nitrate export by 11-digit HUC subbasin.

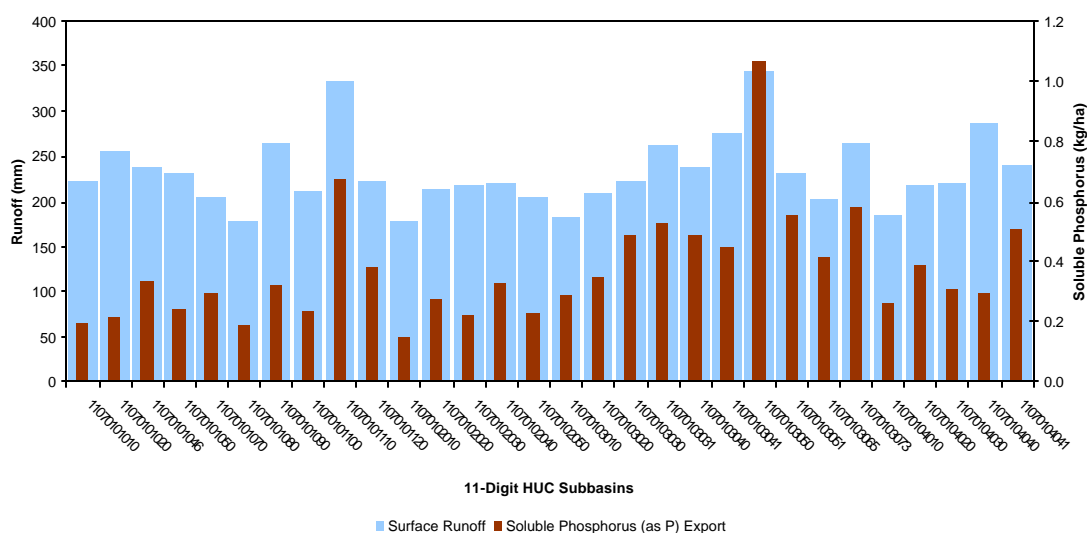


Figure 3.8-20
Comparison of estimated average annual runoff and soluble phosphorus export by 11-digit HUC subbasin.

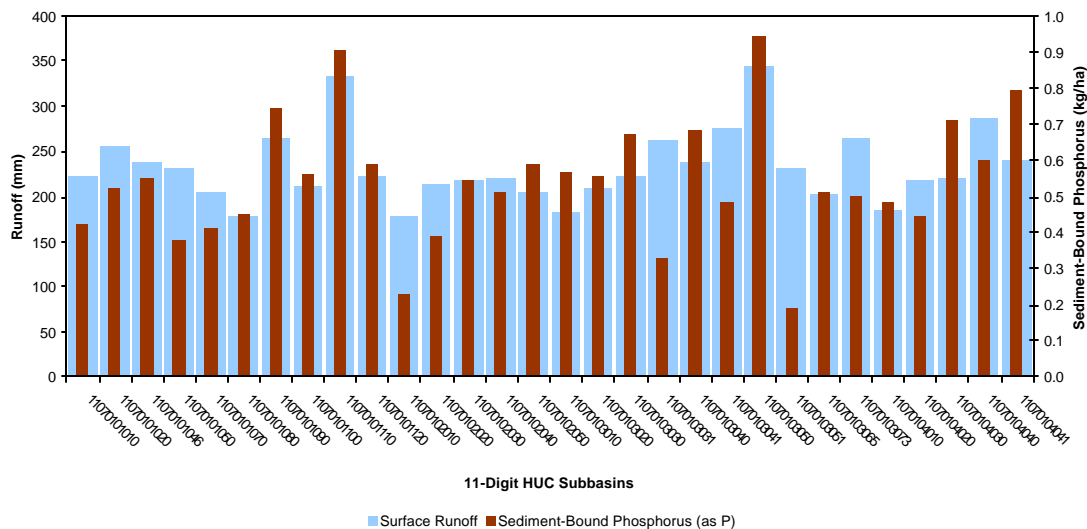


Figure 3.8-21
Comparison of estimated average annual runoff and sediment-bound phosphorus export by 11-digit HUC subbasin.

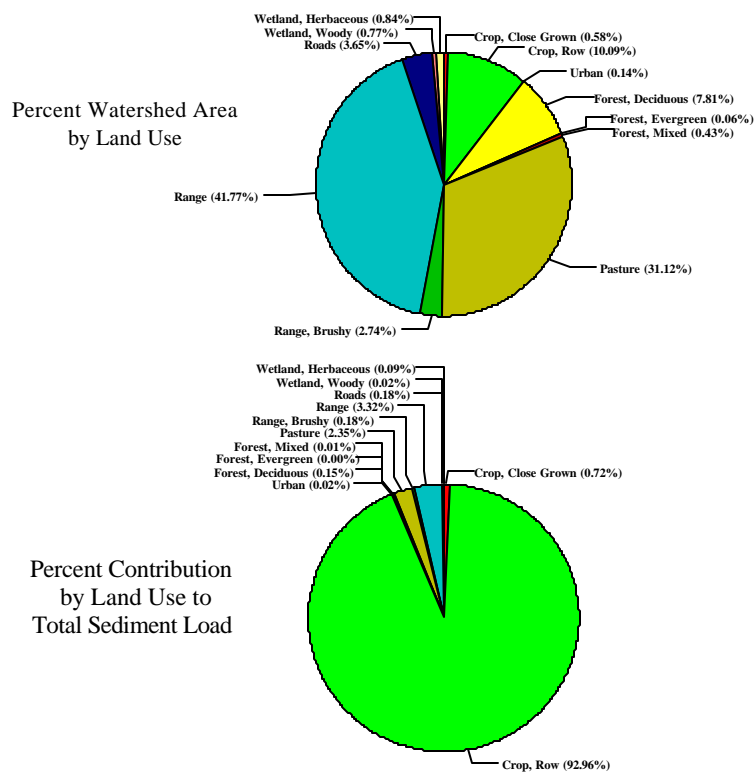


Figure 3.8-22
Comparison of percent Oologah Lake watershed area by land use and contribution to estimated annual average basin-wide sediment load.

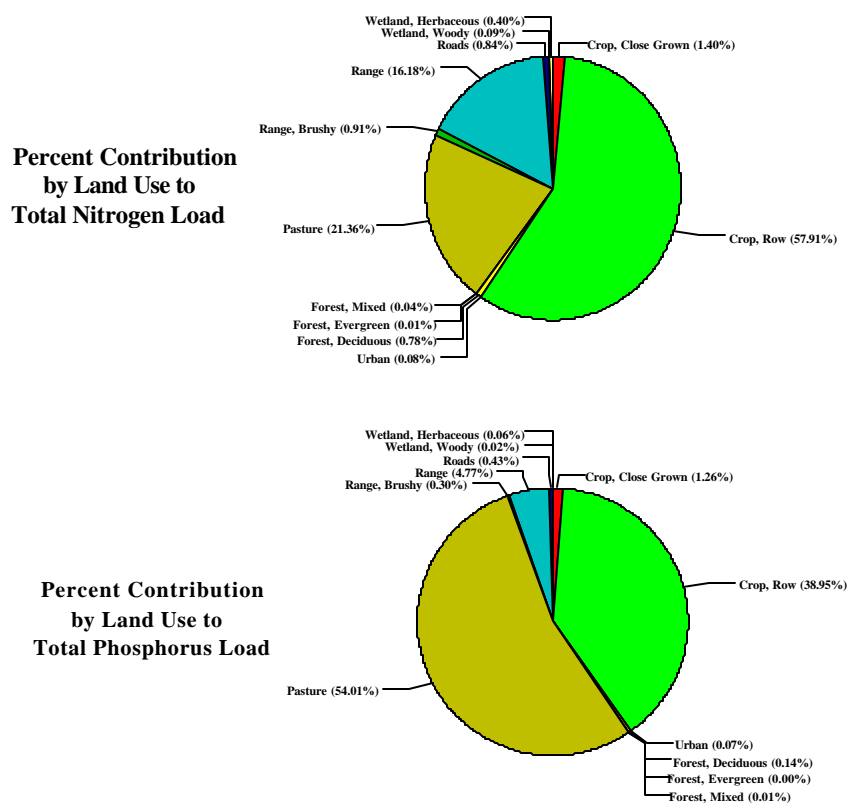


Figure 3.8-23
Contribution by land use in the Oologah Lake watershed to estimated
annual average basin-wide total nitrogen and total phosphorus load.

4.0 DISCUSSION

Data collected during the second year of this study have continued to shed considerable light on the limnology of Oologah Lake and water quality of its major tributaries. The continued collection of current water quality data has enabled the Tulsa District to increase the understanding of factors affecting loading rates, solids dynamics, nutrient/algae relationships, light and temperature regimes, contaminant issues, and a variety of other water quality-related factors that influence ecological integrity, recreational aesthetics, and water supply suitability of Oologah Lake.

With few exceptions, concentrations of chemical constituents at the tributary sites (Verdigris River near Lenapah [LEPO2] and Big Creek near Childers [CHBO2]) were similar between the two study years. In the Verdigris River, mean concentrations of total alkalinity, total hardness, total Kjeldahl nitrogen, nitrite + nitrate, total phosphorus, dissolved phosphorus, and turbidity were statistically significantly ($p < 0.05$) less in 2001 relative to concentrations present in 2000. At Big Creek, fewer significant differences between constituent concentrations were observed between the two study years. Those constituents that were found to differ significantly ($p < 0.05$) between study years at Big Creek included total alkalinity, dissolved Kjeldahl nitrogen, and turbidity.

The continuous monitoring of dissolved oxygen, pH, specific conductance, turbidity, and water temperature, as well as discharge and stage, was continued at major tributaries to Oologah Lake through the second year study. The ranges of dissolved oxygen, pH, specific conductance, turbidity, and water temperature were similar between both the two tributary sites and between study periods at each site. Mean concentrations, with the one exception of turbidity, were slightly higher at CHBO2. The major distinction between the first year and second year studies was in discharge. At CHBO2, discharge ranged from 0 cubic feet per second (cfs) to 2885 cfs, and the mean discharge during year two (81 cfs) was 50% less than that observed during year one. At LEPO2, discharge ranged from 33 cfs to 44,287 cfs with a mean discharge of 1510 cfs, representing an 18.7% decrease in mean discharge during the second year of this study.

Regression equations derived using continuously monitored parameters were adjusted to include data collected during the second year. Following incorporation of the second year data from the tributaries, median RPDs for total alkalinity, total hardness, TDS, chloride, TOC, total phosphorus, dissolved phosphorus, and dissolved ortho-phosphorus were less than 25% at both stations. In addition, parameters having RPDs less than 25% included total calculated nitrogen (TKN + NO₂ - NO₃) and TKN at LEPO2. Estimated concentrations of TSS and dissolved sulfate had RPDs greater than 25% at both stations, and total calculated nitrogen and TKN had RPDs greater than 25% at CHBO2. Of the 12 regression equations derived for each station, 8 at LEPO2 and 7 at CHBO2 explained greater than 80% of the constituent variability.

As was observed during the first year study, the two most common continuously monitored surrogate parameters of importance to regression equations were turbidity (15 of 24 equations) and specific conductance (16 of 20 equations). At LEPO2, the coefficient of determination (R²) of equations for alkalinity, hardness, TOC, and TKN indicate a decrease in the predictive capabilities of the equations. Equations for which the R² was improved included TDS, TSS, chloride, sulfate, and total phosphorus. At CHBO2, the R² of equations for alkalinity, sulfate, and TOC indicate a decrease in the predictive capabilities of the equations. Regression equations for which the R² improved included hardness, TDS, TSS, chloride, and total phosphorus.

Sampling activities at Oologah Lake during 2001 were helpful in further assessing the spatial and temporal variability of water quality parameters within the reservoir. Data collected during this second year study have helped to further define the influence of suspended solids and hydrology on nutrients, light regimes, and algal productivity. In addition, the nature of thermal stratification and hypolimnetic anoxia observed during this study indicate that in the lacustrine portions of the reservoir hydrologic conditions can dramatically impact the duration and intensity of these patterns more than was previously thought. In the more riverine and riverine transitional portions of the reservoir, wind intensity and duration appear to be the variables that most impact vertical thermal and oxygen gradients.

Analysis of C:N ratios for the reservoir indicate that the majority of organic matter (organic carbon and organic nitrogen) in the reservoir indicate that internal (autochthonous) loadings of nitrogen may be more important than previously hypothesized. The overall lake mean C:N ratio was 8.4 in 2000 and 13.35 in 2001. It is widely accepted that C:N ratios of less than 30 are indicative of systems with a high degree of internal loading of organic matter (i.e., decomposition of phytoplankton). The reverse is the case for loadings of phosphorus. Although median estimated loadings of nutrients and suspended solids were lower in 2001, phosphorus was present in measurable concentrations at each sampling site and on each sampling date. Given the degree to which phosphorus will adsorb to clays as well as the turbid nature of Oologah Lake, external (allochthonous) loading and sediment resuspension appear major factors contributing to phosphorus loadings in the reservoir. Relatively strong correlations between total phosphorus ($r > 0.7$, $p < 0.1$) with TSS and turbidity as well as the spatial distribution of phosphorus within the reservoir indicate this to be the mechanism of phosphorus loading.

Continued investigation of the importance of the light regime to phytoplankton productivity in Oologah Lake continued through the 2001 study period. Light penetration in Oologah again showed a distinct spatial trend with water clarity being highest near the dam and diminishing up lake. Of the total light energy reaching the water, a portion is scattered and the remainder absorbed by the water, dissolved compounds, and suspended matter. The sum total of this reduction of radiant energy is light attenuation. The attenuation coefficient is an expression of the exponential attenuation of irradiance at depth compared to that at the surface (Wetzel, 1983). Calculated light attenuation coefficients (η) ranged from 0.92 m^{-1} (Site 1, 8 August 2001) to 12.54 m^{-1} (Site 5, 17 July 2001), with an overall lake mean of 3.90 m^{-1} . The mean η for the lake implies $> 90\%$ light attenuation per meter for the lake as a whole. Mean η 's at each sampling site ranged from 1.98 m^{-1} at Site 1 to 7.73 m^{-1} at Site 5. A trend indicating increasing light attenuation moving from the dam site (Site 1) to the upper portion of the lake (Site 5) was apparent. Observed light attenuation in 2001 was not found to be significantly different from observations in 2000.

The euphotic zone extends from the lake surface to the depth where light dims to about 1% of that at the surface. This zone is the region of net oxygen production during the day by plants (Horne and Goldman 1994). Available light levels below the euphotic zone are too low for photosynthesis to occur. Euphotic depth ranged from 0.38 m (Site 5, 17 July 2001) to 4.97 m (Site 1, 8 August 2001), with an overall lake mean of 1.75 m. Mean euphotic depths at each station ranged from 0.71 m (Site 5) to 2.99 m (Site 1). The trend of decreasing euphotic depth from the dam site to the upper portion of the lake was again observed in this study. The estimation of the true euphotic zone depth (Z_{EU}) in 2001 was not found to be significantly different when compared to estimates of Z_{EU} from the 2000 study.

Secchi disk transparency is a function of the reflection of light from its surface, and thus influenced by the absorption characteristics of the water and its dissolved and suspended particulate matter. Secchi depth (SD) roughly corresponds to the depth of about 10% of surface light (Wetzel 1983). Secchi depths ranged from 0.09 m (Site 5, 19 June 2001) to 1.40 m (8 August 2001), with a lake-wide mean of 0.48 m. Mean SD at each station ranged from 0.17 m (Site 5) to 0.78 m (Site 1). The spatial distribution of SD mirrored that of estimated euphotic depth, with SD decreasing from the dam site to the upper portion of the lake. Secchi depth did not differ significantly from observation in 2001. Empirical data suggest a relationship between the light attenuation coefficient and SD of $\eta = 1.7/DS$ (Wetzel 1983). This relationship in Oologah Lake, based upon whole lake data, is approximately correct for the reservoir.

Nitrogen to phosphorus (N:P) ratios are commonly used in evaluation of nutrient limitation in lakes. An approximate N:P of > 10 is generally considered indicative of phosphorus limitation while a ratio of < 10 indicates nitrogen limitation (Horne and Goldman 1994). Cooke *et al.* (1986) proposed N:P of > 20 as indicative of phosphorus limitation and ratios < 13 evidence that nitrogen may be limiting. When considered together, recommended evaluation methods of both sources would conclude that $N:P < 10$ supports the hypothesis of nitrogen limitation. The overall Oologah Lake-wide average N:P based on total concentrations of each element for this study period was 8.3, representing an increase in the N:P ration of 3.8% relative to 2000. The median N:P ratio was 6.8. By site, average N:P was lowest at Site 5 (4.8) and

increased in the down-reservoir direction to a high of 10.7 at Site 2. At Site 1, the average N:P was 10.5.

Algal dynamics for 2001 will be discussed in an addendum to this report once identification and enumeration of 2001 phytoplankton samples is completed. Although the algal density component is absent in this analysis, a preliminary definition of the trophic status of Oologah Lake can be determined based upon the chlorophyll *a* concentrations present during this study. Average chlorophyll *a* concentrations were 16.7% less than concentrations present in 2000. The average concentration, by sampling site, ranged from 3.8 µg/l (Site 1) to 14.9 µg/l (Site 5), with a whole-lake average of 7.7 µg/l. Generally, chlorophyll *a* concentrations were greatest at Site 5 and decreased in the down-reservoir direction with the lowest chlorophyll *a* concentrations present at Site 1. Chlorophyll *a* concentrations were used to assign a trophic state to Oologah Lake in accordance to equation described by Carlson (1977). The Carlson trophic State index (TSI) in the reservoir ranged from 32 (oligotrophic) to 62 (slightly hypereutrophic), with a mean TSI of 48.2 (mesotrophic).

Diesel range total petroleum hydrocarbons (DRO-TPH) in water and sediment samples from Oologah Lake were measured in some samples collected during this study. Concentrations in both media were low and at or near analytical quantitation limits. Again, no clear pattern of TPH contamination was revealed in either lake-water samples or sediment samples, and no significant differences were noted between study years in sediment TPH concentrations. Lake-water TPH concentrations exhibited trends noticed in the 2000 study with a significant negative correlation between concentrations present in the lake and lake elevation. The highest TPH concentration was found in the lake on 18 September 2001 when the pool elevation was the lowest when TPH was sampled.

Sediment sampling conducted during this study was restricted to the five fixed sampling sites in the thalweg of the reservoir. Sediments were analyzed for physical parameters, general inorganic parameters (see Section 3.6.2 for a complete list), organic carbon, petroleum hydrocarbons, metals (see Section 3.6.5 for a complete list), herbicides and pesticides, and semi-volatile organics. With respect to the physical parameters, the longitudinal distribution of

sediment particle sizes exhibited a more typical distribution during this study. In the main pool of the reservoir, clay-sized and silt-sized grains equally dominated sediments. The percent composition of the sediments comprised of silt-sized grains generally increased in the up-reservoir direction with the proportion of clay-sized grains decreasing in the up-reservoir direction. Concentrations of pesticides and herbicides were again below detectable concentrations.

Concentrations of the 23 metals measured in lake sediments were similar to concentrations in 2000, with no significant difference between the two study periods identified with the exception of cadmium. Median cadmium concentrations for 2001 samples were significantly lower than concentrations present in 2000. A number of metals in Oologah Lake sediments were found to exceed background values typical for freshwater sediments; however, none of these metals concentrations appear to be excessively high or at levels posing significant potential risk to ecological receptors.

Total organic carbon in sediment samples for Oologah Lake was again found to be present in extremely low concentrations and again exhibited a rather atypical distribution relative to other Tulsa District impoundments. Interestingly, median TOC concentrations in the sediments were significantly lower than concentrations present in 2000, with the mean concentration in 2001 64.9% lower. Several factors are thought to contribute to the lower sediment TOC concentrations, including hydrologic influences and rates of primary productivity. Hydrologically, Oologah Lake was very different during the two study periods. In 2000, the hydraulic residence time (calculated from discharge at the dam) was calculated to be 195 days while in 2001, the hydraulic residence time was calculated to be 450 days resulting in less flushing as well as a decrease in the already low allochthonous inputs from the Verdigris River and Big Creek. In addition, the relatively shallow euphotic zone would indicate that autochthonous production does not heavily influence the TOC concentrations in the reservoir (water and sediments); however, C:N ratios of lake-water samples would indicate that organic carbon loadings in the reservoir are autochthonous in nature. A third factor that potentially influences TOC in the sediment is the impact of high inorganic particle sedimentation rates in "diluting" settled organic carbon.

An ultimate goal of this project is development of site-specific tools for predictive evaluation of watershed and/or in-lake management strategies on water quality in Oologah Lake. Reservoir simulations will be conducted using CE-QUAL-W2, a two-dimensional hydrodynamic and water quality model. For this study period, considerable progress was made in preparing the model for site-specific use at Oologah Lake. Updated bathymetric data were used in model grid preparation and proved valuable in hydrologic calibration. The model was found to closely simulate pool elevations when gaged inflows were provided as model input. Next, meteorological data and model parameters affecting reservoir temperature stratification were applied to CE-QUAL-W2 simulations for Oologah Lake. Model output was found to closely simulate the often transitory nature of the vertical temperature regime which characterizes Oologah Lake. Hydrologic and temperature calibration are a significant step toward calibration for other water quality parameters (e.g., solids, algae) as these parameters are largely influenced by temperature stratification and advection. Future study efforts will be focused on completion of model calibration and use of this valuable tool in evaluation of lake management strategies.

The Soil and Water Assessment Tool (SWAT), Version 2000 (Neitsch et al., 2001) was selected to process digital information to estimate average annual sediment yield and nitrogen and phosphorus loading from the Oologah Lake watershed by generalized land use. Watershed modeling in the Oologah Lake watershed requires spatially referenced digital data describing elevation, land use/land cover, soil types and attributes, and weather. Land use in the Oologah Lake watershed, encompassing 1.1 million hectares in Oklahoma and Kansas, is dominated by unmanaged rangelands (40%), pasture/hay land (30%), crop lands (11%), and forests (8%). The SWAT model of the Oologah Lake watershed, divided into 30 subbasins defined by 11-digit HUC watersheds, was hydrologically calibrated using discharge records from USGS gaging station in the watershed with unregulated flow.

Since calibration of sediment and nutrient export in the SWAT model of the Oologah Lake watershed has not yet been performed, reported values for these parameters should be viewed in relative rather than absolute terms. Results identify the relative magnitude of subbasin and land use contributions to sediment yield and nutrient export. Simulated average annual basin-wide

precipitation was 985.6 mm (38.8 in.) over the 45-year simulation period, with 229.6 mm/yr (9.04 in./yr) surface runoff. Runoff carried an estimated annual average 5.16 metric tons (t) of sediment per hectare per year, 4.80 kg/ha/yr organic nitrogen (as N), 1.26 kg/ha/yr nitrate (as N), 0.37 kg/ha/yr soluble phosphorus (as P), and 0.49 kg/ha/yr sediment-bound phosphorus (as P).

Subbasins with a higher percentage of agricultural land uses tended to have higher average annual sediment and nutrient export rates. Predicted average annual sediment loading rates are highest for crop land (47.49 t/ha for row crop and 6.43 t/ha for close grown crop) and lowest for forests (average of 0.10 t/ha). Land uses accounting for the greatest percentage of total basin land area, range and pasture, have predicted average annual export rates of 0.41 and 0.39 t/ha, respectively. Similarly, average annual nutrient export rates are highest for agricultural uses (34.8 kg/ha total nitrogen and 3.3 kg/ha total phosphorus for row crop) in the watershed. Nutrient export rates for pasture (4.2 kg/ha total nitrogen and 1.5 kg/ha total phosphorus) are significantly greater than range land (2.4 kg/ha total nitrogen and 0.1 kg/ha total phosphorus) due, in part, to the modeled assumption that these are managed pasture lands that receive fertilization from animal manure and commercial fertilizers.

Calculation of average annual loading in terms of kg (or t) per year by land use weights export rates by respective land use area. On an average annual basis, the model predicted that 93% of sediment exported from the basin originated from agricultural land uses. Other land uses contributing significantly to sediment export, based mostly on areal extent, were pasture (2.4%) and range (3.5%). Average annual nutrient export by land use follows a similar but slightly less dramatic pattern. Agricultural land uses account for 60% of total nitrogen export with pasture and range lands contributing 21.3% and 17.1%, respectively. Contributions to average annual total phosphorus export were dominated by pasture (54%) and agricultural (40%) land uses.

Future revisions of the SWAT model of the Oologah Lake Watershed would include sediment and nutrient calibration of the model, and modeling of nutrient dynamics in streams and reservoirs. Continued refinement of the model will allow for the analysis of management practices in the watershed affecting sediment and nutrient loading to Oologah Lake.

5.0 INTERIM CONCLUSIONS AND RECOMMENDATIONS

Major findings and conclusions for this period of study (as previously presented in the executive summary of this report) are provided below. Findings are provided separately for tributary data, Oologah Lake general limnology, water quality contaminants, sediment sampling and analysis, and watershed land-use characterization and modeling.

5.1 Oologah Lake Tributaries (Verdigris River and Big Creek).

1. Consistent with results obtained during the initial year of study (2000), substantial differences in concentrations of several key constituents were noted in samples from the two tributaries. Most notably, concentrations of turbidity, total suspended solids, chlorophyll *a*, Kjeldahl nitrogen, and total phosphorus were substantially higher in samples from the Verdigris River relative to those from Big Creek. For both study years combined, average concentrations of total phosphorus, nitrogen, and nephelometric turbidity in samples from the Verdigris River were approximately twice those measured in samples from Big Creek.
2. Total phosphorus (P) concentrations in both tributaries were high, though lower than those measured for the same time period in 2000. For April through September 2001, mean and median total P were 0.11 and 0.09 mg/l, respectively, in samples from the Verdigris River and 0.07 and 0.04 mg/l, respectively, in samples from Big Creek. For the Verdigris River, statistically significant differences in mean concentrations of total P, dissolved total P, and dissolved ortho-P were noted between sampling periods (year 2000 means > year 2001 means). Based on median values, approximately one-half of total P concentrations in samples from both systems were associated with suspended matter.
3. For Verdigris River inflows (April 2000 through September 2001), nitrogen to phosphorus ratios (N:P) were 6.1 and 10.8 based on mean and median concentrations, respectively.

4. Temporal changes in nephelometric turbidity closely mirrored the hydrograph in both tributaries. Based on continuous monitoring data for the study period, mean and median turbidity values were 119.65 and 40.80 nephelometric turbidity units (NTU), respectively, for the Verdigris River (n = 4,294) and 46.95 and 18.10 NTU, respectively, for Big Creek (n = 2,640). For the entire period of April 2000 through July 2001, average turbidity in the Verdigris River was 46.33 (n = 9,882).

5. Tributary-specific multiple regression equations for estimating important physical and chemical parameters based on continuously monitored field data were developed and appeared reasonable for use in estimation of delivered loads. For the Verdigris River, selected equations based on the entire period of record (2000 and 2001) were capable of explaining approximately 83, 58, 84, and 86% of the observed variability in total suspended solids, total organic carbon, total nitrogen, and total phosphorus, respectively. The R^2 value for the total P equation was improved by 0.13 with the addition of data from the second year of study. A similarly derived equation was capable of explaining 97% of the observed variability in total P in Big Creek samples. Nephelometric turbidity was among selected surrogate parameters in regression equations for most constituents.

6. Multiple regression equations were used to estimate average combined daily loads (kg/day) from both tributaries for the April 2000 to September 2001 period as follows: total P (1,690), total nitrogen (11,350), and total suspended solids (1,340,620 kg/day or approximately 1,500 tons/day). Of these loads, relative contributions from the Verdigris River were as follows: total P (92%), total N (96%), and total suspended solids (87%).

5.2 Oologah Lake (General Limnology).

1. Total P concentrations for the study period ranged from 0.02 to 0.30 mg/l, with a mean and median concentration of 0.098 and 0.076 mg/l, respectively. Both concentration and variability increased from Oologah Dam to uplake stations, particularly in shallow water areas above Winganon Bridge. Total P concentrations were strongly correlated with suspended solids. Mean and median total P concentrations for this study period were approximately 11 and 8%

lower, respectively, than those for the same period in 2000, but this difference was not statistically significant.

2. Measurable concentrations of dissolved ortho-P were reported for nearly every sample collected during this study period. Concentrations of dissolved ortho-P ranged from 0.01 to 0.12 mg/l, with nearly identical mean and median values of 0.044 and 0.046 mg/l, respectively. These values were nearly identical to those observed during the initial year of study.

3. Mean lake-wide nitrogen to phosphorus ratio (N:P) was 8.3. This value was nearly identical to that measured in 2000 (8.0). Accordingly, under conditions when nutrient concentrations limit algal growth, N:P derived during both study periods support a hypothesis of nitrogen limitation in Oologah Lake – a condition somewhat unusual for reservoirs of the region.

4. Consistent with the first year of study, turbidity values in Oologah Lake frequently exceeded the State of Oklahoma lake water quality standard of 25 NTU. Surface field turbidity across all sampling sites and dates ($n = 41$) ranged from 8 to 282.1 NTU, with mean and median values of 62.7 and 49.5 NTU, respectively. Mean and median surface turbidity values were 9.5 and 7.7% higher relative to surface turbidity in 2000 though differences were not statistically significant. Turbidity levels were greatest and highly variable at up-lake stations relative to those at near-dam water supply intake locations.

5. Lake-wide concentrations of chlorophyll *a*, a commonly used indicator of algal production, ranged from 1.2 to 25.6 $\mu\text{g/l}$, with mean and median concentrations of 7.7 and 6.9 $\mu\text{g/l}$, respectively. While median whole lake chlorophyll concentrations were not significantly different between study years, chlorophyll *a* concentrations exhibited lower variability in 2001 relative to those measured in the initial year of study. On several dates during the study, vertical profiles (1 m increments) of both chlorophyll *a* and pheophytin *a* (a degradation pigment and by-product of algal senescence) were measured at Oologah Dam. Preliminary findings are presented in this report.

6. For this study period, Secchi depths (SD) ranged from 0.09 to 1.40 m, with an overall lake average of 0.48 m. Mean SD was highest near Oologah Dam (0.78 m) and lowest near at the upper end of the lake (0.17 m).

7. Average estimates of euphotic zone depth (Z_{eu}) for this study period were very similar to those obtained during the initial year of study. Data from both years reveal the presence of a very limited layer of light intensity suitable for algal production in Oologah Lake. Calculated photic zone depths ranged from 0.38 to 4.97 m, with an overall average of 1.75 m (5.7 feet) for the lake through the sampling period. When data for both study periods were combined, mean photic zone depths ranged from 0.82 m (2.7 feet) at the upper end of Oologah Lake to 2.74 m (9 feet) near Oologah Dam. Site-specific ratios of Z_{eu} :SD were derived permitting estimation of photic zone depth based solely on SD. For all data (2000–2001), these values ranged from 3.64 to 4.52.

8. During this study period, patterns of both thermal and dissolved oxygen (DO) stratification were fairly similar to those observed during the initial year of study. However, observed differences included a more prolonged period of hypolimnetic anoxia at near-dam sites and differences in overall magnitude of temperature decreases with depth in the lower portion of the reservoir. Relative contributions of reservoir outflow and meteorology to vertical stratification patterns are discussed.

9. A new bottom contour map of Oologah Lake was completed using previously-collected data consisting of approximately 1.2 million georeferenced data points with z -values corresponding to bottom surface elevation. This updated information was employed in reservoir modeling exercises. The map is available in geographic information system (GIS) format.

10. A significant task during this study period was continued set up and calibration of a hydrodynamic and water quality model (CE-QUAL-W2) for Oologah Lake. The ultimate goal of this model will be to provide a valuable tool for evaluation of lake management strategies. The model computational grid was refined using updated bathymetric data, and the model was able to successfully reproduce hydrologic dynamics of the reservoir. In addition, initial

temperature calibration of the model was accomplished and output was capable of closely simulating relatively transitory vertical temperature dynamics of the system. Future efforts will include continued calibration for other water quality constituents.

5.3 Oologah Lake (Water Quality Contaminants).

1. On four sampling dates toward the end of the study period, water samples were collected and analyzed for diesel range organics (DRO) total petroleum hydrocarbons (TPH). While detectable concentrations were present in 30% of these samples, concentrations were low and at or near low-level quantitation limits. The range of detected concentrations was 102 to 494 µg/l (parts per billion). Detection frequency and concentrations were similar to those observed over a more extended sampling period in 2000 (USACE 2001). A statistically significant, negative correlation was observed between lake-wide mean surface water TPH concentration and lake surface elevation during the initial year of study. Though sample numbers were limited for 2001, TPH detection frequency and average concentration were highest on 18 September 2001 when pool elevation was the lowest (637.56 feet) of the sampling dates.

2. Total and dissolved concentrations of a wide range of metals were measured in water samples from Oologah Lake through 19 June 2001 during this study. Concentrations of most toxic metals were generally below sample quantitation limits. In the initial year of study, an anomalous condition was observed on one sampling date when concentrations of cadmium and chromium exceeded raw water criteria in samples across the lake (USACE 2001). Similar conditions were not observed during this study period. Concentrations of chromium were below quantitation limits (0.025 mg/l) in all samples, and the maximum detected cadmium concentration was 0.006 mg/l. Consistent with results obtained during the initial year of study, metals concentrations did not appear to be at concentrations of concern in Oologah Lake waters.

5.4 Oologah Lake (Sediments).

1. Oologah Lake sediment samples were dominated by clay- and silt-sized grains. Longitudinal gradients of particle size were more typical of those common to reservoirs relative to results obtained in 2000. Though sample sizes for both years are limited, this more typical sedimentation pattern in 2001 may reflect the influence of lower inflow conditions on sediment sorting relative to that of higher flow events experienced in 2000.
2. Total organic carbon (TOC) concentrations reported for 2001 Oologah Lake sediment samples were extremely low and similar at all sampling sites. Sediment TOC concentrations were considerably lower than those measured at the same sites in 2000 and median concentrations were statistically distinct. Concentrations from both years were considerably lower and exhibited atypical distributional patterns relative to other Oklahoma reservoirs.
3. Extractable (diesel range) TPH concentrations were measured in Oologah Lake main pool sediments on 8 August 2001. Detectable concentrations were present in most samples but were low and near the quantitation limit. Concentrations ranged from <0.5 to 22.7 mg/Kg. When compared to results from August 2000 sampling from the main pool of Oologah Lake, concentrations were more variable among sites but median concentrations were not statistically different. Consistent with results of previous sediment investigations at Oologah Lake, detection of TPH in sediments was not associated with detectable concentrations of compound-specific organics (i.e., semi-volatile organics) or elevated metals concentrations that often accompany petroleum contamination.
4. Concentrations of many total metals in Oologah sediment samples collected 8 August 2001 exceeded typical “background” concentrations for freshwater sediments and northeastern Oklahoma surface soils. Concentrations were similar to those measured during the initial year of study. When evaluated using conservative screening level criteria, no metals were excessively high or at levels posing significant potential risk to ecological receptors.

5. Concentrations of organochlorine pesticides, chlorinated herbicides, organophosphorus pesticides, and semi-volatile organics were below analytical quantitation limits in all sediment samples collected in 2001. Owing to detection of very low levels of atrazine in limited water samples collected in 2000 (USACE 2001), this compound was added to the analyte list for sediment samples collected in 2001. Concentrations were below the analytical quantitation limit (167 ug/Kg) in all samples.

5.5 Watershed Land-Use and Modeling.

1. The Soil and Water Assessment Tool (SWAT), Version 2000 (Neitsch et al., 2001) was selected to process digital information to estimate average annual sediment yield and nitrogen and phosphorus loading from the Oologah Lake watershed by generalized land use. Watershed modeling in the Oologah Lake watershed required spatially referenced digital data describing elevation, land use/land cover, soil types and attributes, and weather.

2. The Oologah Lake watershed is defined by four 8-digit USGS hydrologic cataloging units (HUCs) including 11070101 (Upper Verdigris, Kansas), 11070102 (Fall, Kansas), 11070103 (Middle Verdigris, Kansas and Oklahoma) and 11070104 (Elk, Kansas). Each of these 8-digit HUCs is further subdivided into 11-digit HUCs that were used as the basis for subbasins modeled within SWAT.

3. The Oologah Lake watershed encompasses 1.1 million hectares in Oklahoma (19%) and Kansas (81%). Based on USGS (2000) National Land Cover Data, unmanaged grasslands account for 40% of the total basin area, managed pasture/hay land accounts for 30%, crop lands 11%, forests 8%, and the remainder is distributed between other minor land uses.

4. Mean annual total, base, and surface runoff discharge estimates from the SWAT model were adjusted to match, as closely as possible, the estimates made from historical discharge data at selected gaging stations with unregulated flow. The calibrated SWAT model of the Oologah Lake watershed was run for a 45-year period based on the coincident period of record (1955–1999) of the available weather stations. Since calibration of sediment and nutrient

export in the SWAT model of the Oologah Lake watershed has not yet been performed, reported values for these parameters should be viewed in relative rather than absolute terms. Results identify the relative magnitude of subbasin and land use contributions to sediment yield and nutrient export.

5. Simulated average annual basin-wide precipitation was 985.6 mm (38.8 in.) over the 45-year period, with 229.6 mm/yr (9.04 in./yr) surface runoff. Runoff carried an estimated annual average 5.16 metric tons (t) of sediment per hectare per year, 4.80 kg/ha/yr organic nitrogen (as N), 1.26 kg/ha/yr nitrate (as N), 0.37 kg/ha/yr soluble phosphorus (as P), and 0.49 kg/ha/yr sediment-bound phosphorus (as P).

6. Subbasins with a higher percentage of agricultural land uses (row crops) tended to have higher average annual sediment export rates. A similar pattern existed for nutrient export in the Oologah Lake basin. Subbasins with a greater percentage of land area designated as crop tend to have higher average annual export rates. Predicted average annual sediment loading rates are highest for crop land (47.49 t/ha for row crop and 6.43 t/ha for close grown crop) and lowest for forests (average of 0.10 t/ha). Land uses accounting for the greatest percentage of total basin land area (excluding water), range (41.8%) and pasture (31.1%), have average annual export rates of 0.41 and 0.39 t/ha, respectively. Similarly, average annual nutrient export rates are highest for cropland (34.8 kg/ha total nitrogen and 3.3 kg/ha total phosphorus for row crop) in the watershed. Nutrient export rates for pasture land (4.2 kg/ha total nitrogen and 1.5 kg/ha total phosphorus) are significantly greater than range land (2.4 kg/ha total nitrogen and 0.1 kg/ha total phosphorus) due, in part, to the modeled assumption that these are managed pasture lands that receive fertilization from animal manure and commercial fertilizers.

7. Calculation of average annual loading in terms of kg (or t) per year by land use weights export rates by respective land use area. On an average annual basis, the model predicted that 93% of sediment exported from the basin originated from crop lands. Other land uses contributing significantly to sediment export based mostly on areal extent were pasture (2.4%) and range (3.5%). Average annual nutrient export by land use follows a similar but slightly less dramatic pattern. Cropland uses account for 60% of total nitrogen export with

pasture and range lands contributing 21.3% and 17.1%, respectively. Contributions to average annual total phosphorus export were dominated by pasture (54%) and crop (40%) land uses. Urban land use export rates for sediment and nutrients are generally higher than all land uses other than crop land, but they occupy a small areal fraction of the basin and thus contribute only a small fraction of total average annual sediment and nutrient loading.

8. Construction of the model, and its application, requires many assumptions. Limitations and significant sources of uncertainty must be identified. Errors in, and scale of, GIS data contribute significantly to uncertainty of modeled output. The functional modeling units of the SWAT model are combinations of specific land uses and soil types within hydrologically-defined subbasins of the larger watershed. In order to reduce the complexity of the model, not every possible combination of land use and soil type is modeled. Weather data input into the model was collected at relatively few points in the basin. Rainfall can be highly variable, and the limited number of weather stations used in this study cannot effectively describe the actual variability. Pond morphometric data were estimated based on digital land use/cover data. In-stream and reservoir nutrient dynamics were not modeled. Calibration of sediment and nutrient export has not yet been performed. The simulation began before the operational dates of four of the five reservoirs in the watershed. Thus, annual average export rates and loading include periods when these reservoirs were not acting as sediment and nutrient traps in the basin. Point source nutrient inputs were not included in the present modeling effort.

5.6 Recommendations for Further Study. General recommendations for further study include continued limnological data collection at Oologah Lake and continued monitoring of loads of key constituents. It is also recommended the both lake and watershed modeling continue to be refined for holistic evaluation of watershed needs for the Verdigris River Basin. These activities will provide a valuable tool for future assessment of watershed management techniques.

6.0 REFERENCES

- Air Force Combat Climatology Center (AFCCC). 2001. Cooperative weather station data compiled from National Climatology Data Center (NOAA) databases.
- Alexander, R. B., and R. A. Smith. 1990. County-Level Estimates of Nitrogen and Phosphorus Fertilizer Use in the United States, 1945 to 1985. USGS Open-File Report 90-130.
- Arnold, J. G., P. M. Allen, G. Berhardt. 1993. A Comprehensive Surface-Groundwater Flow Model. *J. Hydrol.* 142:47-69.
- Arnold, J. G., J. R. Williams, A. D. Nicks, and N. B. Sammons. 1990. SWRRB: A basin scale simulation model for soil and water resources management. Texas A&M Univ. Press, College Station, TX.
- ASAE. 1991. ASAE Standards. Manure Production and Characteristics.
- Atkinson, S. F., K. L. Dickson, W. W. Waller, L. Ammann, J. Franks, T. Clyde, J. Gibbs, and D. Rolbiecki, 1999. A Chemical, Physical and Biological Water Quality Survey of Lake Texoma: August 1996 – September 1997 Final Report. Prepared for the USACE Tulsa District. Institute of Applied Science, University of North Texas, Denton Texas. June 1999.
- Buiteveld, H. 1995. A Model for Calculation of Diffuse Light Attenuation (PAR) and Secchi Depth. *Netherlands Journal of Aquatic Ecology*, 29(1): 55-65.
- Carlson, R. E. 1977. A trophic state index for lakes. *Limnology and Oceanography*, 23(2):361-369.
- Cederstrand, J. R., and A. Rea. 1995. Watershed boundaries and digital elevation model of Oklahoma derived from 1:100,000-scale digital topographic maps. U.S. Geological Survey. Open-File Report 95-727.
- Christensen, V. G., X. Jian, A. C. Ziegler. 2000. Regression Analyses and Real-Time Water-Quality Monitoring to Estimate Constituent Concentrations, Loads, and Yields in the Little Arkansas River, South-Central Kansas, 1995-99. USGS Water Resources Investigations Report 00-4126.
- Cooke, G. D., E. B. Welch, S. A. Peterson, and T. R. Newcoth. 1986. Lake and Reservoir Restoration. Butterworth Publishers.
- DiLuzio M., R. Srinivasan, J. Arnold. 2001. ArcView Interface for SWAT2000: User's Guide. Blackland Research Center, Texas Agricultural Experiment Station, Temple, TX.
- Horne, A. J., and C. R. Goldman, 1994. *Limnology*. McGraw-Hill, Inc., 576p.

Hyne, N.J. 1978. The distribution and source of organic matter in reservoir sediments. *Environ. Geol.* 2(5):279-287.

Kansas Data Access and Support Center, 2001.
<http://mapster.kgs.ukans.edu/dasc/catalog/coredata.html>.

Kansas Department of Transportation. 1994. Long Range Transportation Plan.

Knisel, W. G. 1980. CREAMS: A field scale model for chemicals, runoff, and erosion from agricultural management systems. U.S. Dept Agric. Conserv. Res. Report No. 26.

Lander, C., and D. Moffit. 1998. Nutrients Available from Livestock Manure Relative to Crop Growth Requirements. USDA-NRCS, February 1998, Resource and Strategic Planning Working Paper 98-1.

Leonard, R. A., W. G. Knisel, and D. A. Still. 1987. GLEAMS: Groundwater loading effects on agricultural management systems. *Trans. ASEA* 30(5):1403-1428.

Lind, O. T., 1985. *Handbook of Common Methods in Limnology*. Second Edition. Kendall/Hunt Publishing Co., Dubuque, IA. 199p.

Long, E. R., D. D. MacDonald, S. L. Smith, and F. D. Calder. 1995. Incidence of adverse biological effects within ranges of chemical concentrations in marine and estuarine sediments. *Environ. Manag.* 19(1):81-97.

MacDonald, D.D., C.G. Ingersoll, and T.A. Berger. 2000. Development and evaluation of consensus-based sediment quality guidelines for freshwater ecosystems. *Arch. Environ. Contam. Toxicol.* 39:20-31.

Minitab, Inc. 2000. Minitab Statistical Software: Release 13. Minitab, Inc.

National Oceanic and Atmospheric Administration (NOAA). 1999. Screening Quick Reference Tables. Coastal Protection and Restoration Division. Hazmat Report 99-1.

Neitsch, S. L., J. G. Arnold, J. R. Kiniry, J. R. Williams. 2001. Soil and Water Assessment Tool: User's Manual, Version 2001. Grassland, Soil and Water Research Laboratory, ARS, Temple, TX.

Reckhow, K. H., and S. C. Chapra. 1983. *Engineering Approaches for Lake Management, Volume 1: Data Analysis and Empirical Modeling*. Butterworth Publishers, Boston, MA.

Thornton, K.W., B.L. Kimmel, and F.E. Payne. 1990. *Reservoir Limnology: Ecological Perspectives*. John Wiley and Sons, Inc., New York, NY.

- Thornton, K.W., R.H. Kennedy, J.H. Carroll, W.W. Walker, R.C. Gunkel, and S. Ashby. 1981. Reservoir sedimentation and water quality – a heuristic model. In: Stefen, H.G. (ed.) Proceedings of the Symposium on Surface Water Impoundments. Amer. Soc. Civil Engr., New York, NY, 654-666 pp.
- U.S. Army Corps of Engineers (USACE). 2000. Project Work Plan and Quality Assurance Project Plan, Oologah Lake, Oklahoma Watershed Study. Tulsa District, Corps of Engineers, Tulsa, OK. March 2000.
- U.S. Army Corps of Engineers (USACE). 2001. Lake Data. <http://www.swt-wc.usace.army.mil/verdigris.html>.
- U.S. Army Corps of Engineers (USACE). 2001. Oologah Lake, Oklahoma, Watershed Study, Interim Report of Findings: April – September 2000. Tulsa District, U.S. Army Corps of Engineers, Tulsa, OK.
- U.S. Army Corps of Engineers (USACE). 1993. Civil Works Projects: Pertinent Data. USACE-Tulsa District, September, 1993.
- USDA - NASS, 1997. NASS AG97 CD-ROM: Ag. Census U.S.A. U.S. Department of Agriculture. <http://www.nass.usda.gov/census/census97>.
- USDA-SCS. 1992. National Engineering Handbook: Agricultural Waste Management Field Handbook. Part 651. April 1992.
- U.S. Geological Survey (USGS). 1984. Element Concentrations in Soils and Other Surficial Materials of the Conterminous United States. USGS Professional Paper 1270.
- U.S. Geological Survey (USGS). 1994. Digital Elevation Models. U.S. Geological Survey. <http://edcwww.cr.usgs.gov/doc/edchome/ndcdb/ndcdb.html>.
- U.S. Geological Survey (USGS). 1999a. NWIS-W Data Retrieval. U.S. Geological Survey. <http://water.usgs.gov/nwis/>.
- U.S. Geological Survey (USGS). 1999b. National Hydrography Dataset. U.S. Geological Survey. <http://edcwww.cr.usgs.gov/doc/edchome/ndcdb/ndcdb.html>.
- U.S. Geological Survey (USGS). 2000. MLRA National Land Cover Data. U.S. Geological Survey. <http://edcwww.cr.usgs.gov/doc/edchome/ndcdb/ndcdb.html>.
- Wahl, T. L., and K. L. Wahl, 1996. BFI - A Computer Program for Computing an Index to Base Flow (Version 4.1W). U.S. Bureau of Reclamation Water Resources Research Laboratory, and U. S. Geological Survey Water Resources Division.
- Wetzel, R. G. 1983. Limnology. W. B. Saunders Co., Philadelphia, PA.

Williams, J. R., A. D. Nicks, and J. G. Arnold. 1985. Simulator for water resources in rural basins. J. Hydrol. Eng. 111(6): 970-986.

APPENDIX A

CE-QUAL-W2 MODELING REPORT

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1 Introduction

Background

Oologah Reservoir is located on the Verdigris River at river mile 90.2, about 2 miles southeast of Oologah in Rogers County, Oklahoma, and about 27 miles northeast of Tulsa in Tulsa County, Oklahoma (Figure 1-1). Project purposes include flood control, water supply, navigation, recreation, and fish and wildlife. The reservoir serves as a primary source of water supply for the city of Tulsa. High inorganic suspended solids and phosphorus loadings characterize the reservoir. The inorganic suspended solids may limit algal growth by limiting light availability. The possibility exists that if inorganic suspended solids loading are reduced, increased algal growth may occur due to decreased light limitation. The U.S. Army Corps of Engineers, Tulsa District (CESWT) needs to develop a tool to assist in determining the effects of watershed management strategies on water quality in Oologah Reservoir. To meet their needs, the CESWT has requested the assistance of the Water Quality and Contaminant Modeling Branch, U.S. Engineer Research and Development Center (ERDC) to provide the CESWT with a tool to determine effects of watershed and operational management changes on in-pool water quality. Model development will be separated into various phases conducted over several years. This report documents progress of this study to date.

Objective

The objective of this research is to develop a tool to assist the CESWT in determining watershed management practices on water quality in the Oologah Reservoir.

Approach

CE-QUAL-W2 is a two-dimensional, longitudinal/vertical hydrodynamic and water quality model that is suitable for applications to rivers, lakes, reservoirs, and estuaries. The model has been successfully applied to over 200 different systems throughout the U.S. and abroad. In addition to computing water surface elevations, horizontal/vertical velocities, and temperature, the model contains 17 additional state variables for describing water quality including algal/nutrient/dissolved oxygen interactions. These are listed in Table 1-1.

The model will be applied to Oologah Reservoir to provide the CESWT with a tool that allows investigating the effects of watershed and operational management strategies on in-pool water quality. Model development will be separated into various phases that will be conducted over the course of several years. The first phase is to develop necessary bathymetry and time-varying boundary conditions, such as meteorology, inflows/outflows, inflow temperatures, and water quality concentrations.

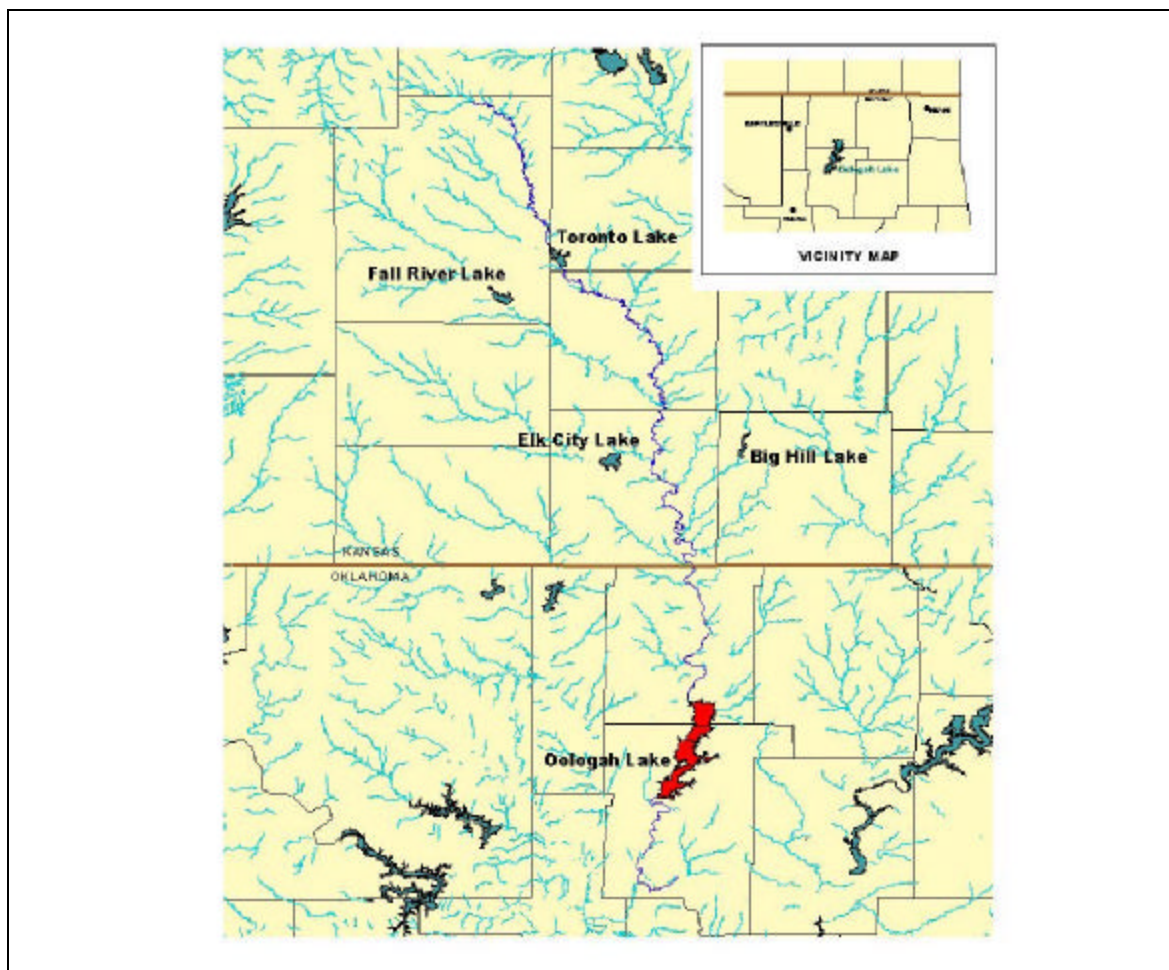


Figure 1-1
Site map of Oologah Reservoir (CESWT, 2000)

Table 1-1
CE-QUAL-W2 Water Quality State Variables

Variable	Name	Variable	Name
1	conservative tracer	10	bioavailable phosphorus
2	coliform bacteria	11	algal biomass
3	total dissolved solids	12	CBOD
4	Inorganic suspended solids	13	dissolved oxygen
5	labile dissolved organic matter	14	sediments
6	refractory dissolved organic matter	15	total inorganic carbon
7	labile particulate organic matter	16	alkalinity
8	Ammonium	17	iron
9	nitrate/nitrite		

2 Input Data

Any successful application of CE-QUAL-W2 requires many different types of data. These data are grouped as follows:

- a. Initial conditions:
 - 1. Bathymetry
 - 2. Water surface elevation
 - 3. Temperature
 - 4. Water quality constituents
- b. Boundary conditions:
 - 1. Inflow/outflow
 - 2. Temperature
 - 3. Water quality
 - 4. Meteorology
- c. In-pool conditions:
 - 1. Temperature
 - 2. Water quality
 - 3. Water surface elevations

These data are used to set initial conditions at the beginning of a simulation and provide time-varying updates that drive the model during the simulation. In addition to these data, other data such as outlet descriptions and tributary and withdrawal locations are also required to complete the physical description of the prototype. In-pool data, including observed water surface elevations, temperatures, and constituent concentrations, are also required during model calibration to assess model performance.

A clear distinction needs to be made regarding the different data types required for calibration. In-pool data have no effect on model performance in that they are only used in assessing model performance. Initial and boundary conditions are of greater importance because they directly affect model performance. For most studies, boundary conditions are rarely collected at a frequency most modelers deem sufficient to accurately describe the forcing functions responsible for the temperature and water quality conditions observed at a project. However, for this study, boundary conditions were collected as recommended by the ERDC to adequately meet modeling requirements.

Bathymetry

CE-QUAL-W2 requires that the reservoir be discretized into longitudinal segments and vertical layers that may vary in length and height. An average width must then be defined for each active cell where an active cell is defined as potentially containing water. Additionally,

every branch has inactive cells at the upstream and downstream segments and top layer. Inactive cells are also located below the bottom active cell in each segment. Segment layer heights for Oologah were constant while segment lengths varied.

Once the segment lengths and layer heights were finalized for Oologah, average widths were determined for each cell. Average widths for Oologah were determined from digitized data provided by the CESWT. The grid for Oologah consisted of four branches with a total of 61 active segments and a maximum of 35 layers vertically one meter (m) thick. Branches 2 – 4 were included to accurately compute the volume of the reservoir and did not include inflows to them. Figure 2-1 shows the configuration of the grid. A comparison of the computed volume-elevation curve with a volume-elevation curve generated from the digitized data in ARC View is presented in Figure 2-2. The only observed volume-elevation curve available was from 1977, which was considered to not represent present bathymetry. As seen from Figure 2-2, the computed volume of the reservoir closely approximated the curve generated from the Oologah digitized data.

In-pool Data

The model was calibrated using observed in-pool profile data and surface samples collected and provided by the CESWT during 2000. Observed data for Oologah Reservoir were collected bi-weekly beginning 18 April 2000 and ending 19 September 2000 for the parameters listed in Table 2-1. Table 2-2 lists for the in-pool stations at Oologah Lake, the station identification number, river mile location, and source of data. Figure 2-3 shows in-pool observed station locations in the reservoir.

Initial Conditions

There are several options available for setting initial conditions in CE-QUAL-W2:

- 1) Initialize all cells in the grid to a single value;
- 2) Initialize all cells in the grid based on vertical variations; and
- 3) Initialize all cells in the grid based on vertical and longitudinal variations.

For calibration, initial conditions at Oologah Reservoir were set to the first date observed data were collected. All water quality variables were initialized using option 1 since there was little variation in concentrations throughout the reservoir.

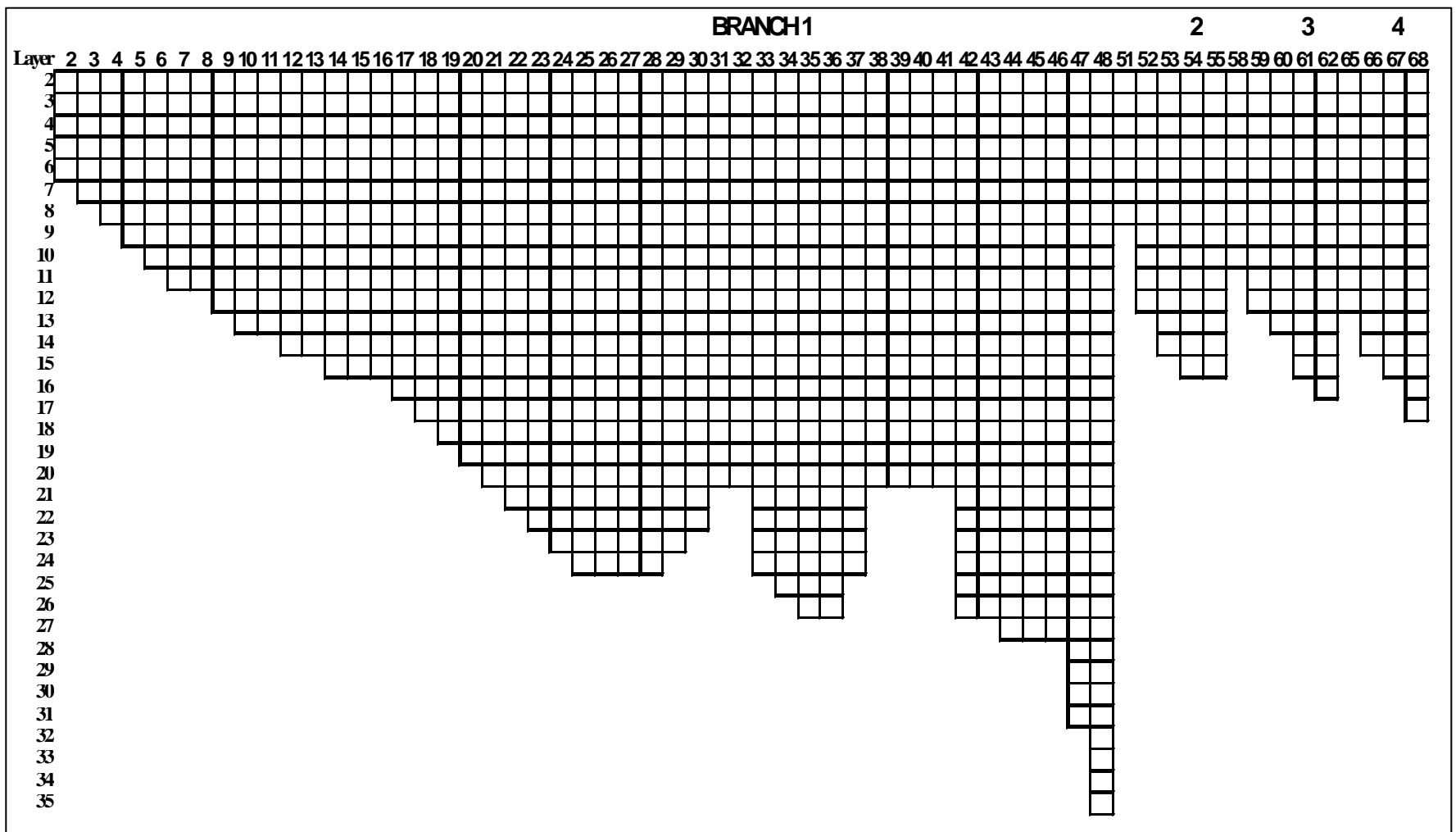


Figure 2-1
Oologah grid

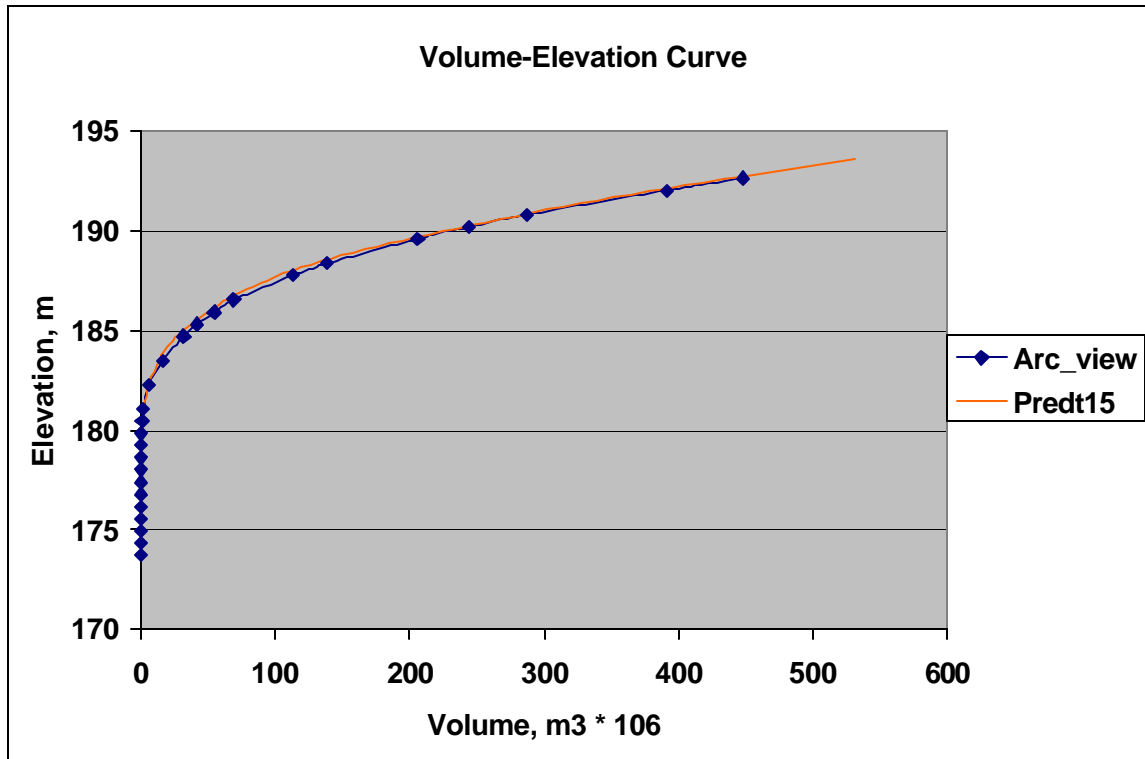


Figure 2-2
Volume-elevation curve comparison

Table 2-1
Water quality constituents of interest collected for Oologah Modeling Study

Temperature (°C)	Dissolved Orthophosphorus (mg/L)
Biological Oxygen Demand (mg/L)	Total Dissolved Phosphorus (mg/L)
Total Organic Carbon (mg/L)	Total Phosphorus (mg/L)
Dissolved Organic Carbon (mg/L)	Solids Settable (mg/L)
Total Iron (mg/L)	Total Dissolved Solids (mg/L)
Dissolved Iron (mg/L)	Total Suspended Solids (mg/L)
Total Magnesium (mg/L)	Volatile Solids (mg/L)
Dissolved Magnesium (mg/L)	Sulfate (mg/L)
Total Manganese (mg/L)	Turbidity (NTU)
Dissolved Manganese (mg/L)	Chlorophyll a (ug/L)
Ammonia-Nitrogen (mg/L)	Total Alkalinity
Total Kjeldahl Nitrogen (mg/L)	Specific Conductance (uS/cm)
Dissolved Kjeldahl Nitrogen (mg/L)	Dissolved Oxygen (mg/L)
Nitrate-Nitrite-Nitrogen (mg/L)	pH
Secchi Depth (m)	Dissolved Oxygen Saturation (%)

Table 2-2
Observed data stations at Oologah Reservoir

Station Number *	Station Name	River Mile	Source
Site 1	OOL-1	90.2	In-pool
Site 4	OOL-2	109.0	In-pool
Site 5	OOL-3	111.0	In-pool
Site 2	OOL-4	97.0	In-pool
Site 3	OOL-5	104.0	In-pool
	VR-1		Tailwater
	VR-2		River
	BC-1		Tributary
* Note station numbers from Figure 2-3.			

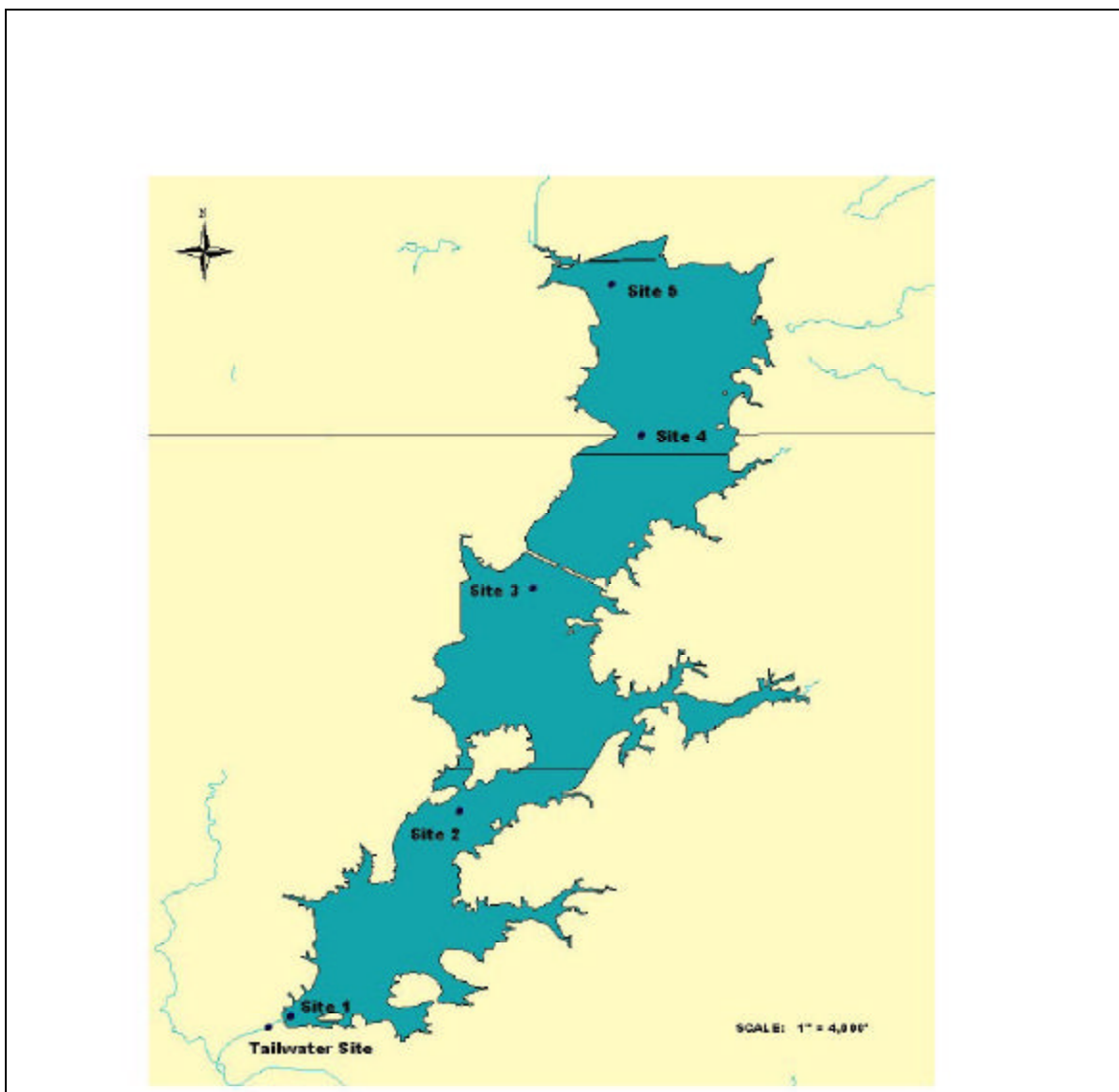


Figure 2-3
In-pool observed data locations (CESWT, 2000)

Boundary Conditions

Inflows and Outflows. The CESWT has identified the Verdigris River and Big Creek as the largest contributors of inflows and loadings to the lake. The CESWT provided hourly inflows, total release flows, and water surface elevations measured for the period of 18 April 2000 through 19 September 2000 for these two tributaries. However, since the grid only went to the most upstream end of the reservoir and did not include the section of the Verdigris River where Big Creek joins, these two inflows were combined to equal the inflow into the reservoir. Figure 2-4 shows the inflows and outflows used during the modeled year.

Inflow Temperatures

CESWT provided hourly inflow temperatures measured for the period of 18 April 2000 through 19 September 2000. Figure 2-5 shows the inflow temperatures for the Verdigris River used during modeled year.

Inflow Constituent Concentrations

Water quality inflow concentrations for other constituents of the main branch of Oologah Reservoir (Verdigris River and Big Creek) were also provided by CESWT. Inflow water quality concentrations were available for all constituents listed in Table 2-2 on a bi-weekly basis except DO which was available on an hourly basis.

Although inflow concentrations of LDOM, RDOM, LPOM, and RPOM were not monitored as such, their boundary concentrations were estimated from total organic carbon (TOC). The assumption was made that the majority of TOC was refractory. To remove the uncertainty of these assumptions, data would have to be collected for the different forms. The equations listed below are the equations used in estimating these constituents from TOC.

$$\text{LDOM} = ((\text{TOC} - \text{algae}) * 0.75) * 0.30 \quad (1)$$

$$\text{RDOM} = ((\text{TOC} - \text{algae}) * 0.75) * 0.70 \quad (2)$$

$$\text{LPOM} = ((\text{TOC} - \text{algae}) * 0.25) * 0.30 \quad (3)$$

$$\text{RPOM} = ((\text{TOC} - \text{algae}) * 0.25) * 0.70 \quad (4)$$

Inflow algal concentrations were estimated from chlorophyll *a* data. CE-QUAL-W2 requires algal concentrations in units of grams of organic matter per cubic meter (gm OM/m³). Measured chlorophyll *a* concentrations were in units of micrograms of chlorophyll *a* per liter (µg chl-*a*/l) and were converted to gm OM/m³ using the conversion factor 65 as recommended by the QUAL2E and CE-QUAL-W2 user manuals (Brown and Barnwell, 1987 and Cole and Buchak, 1995, respectively). The conversion equation is written as:

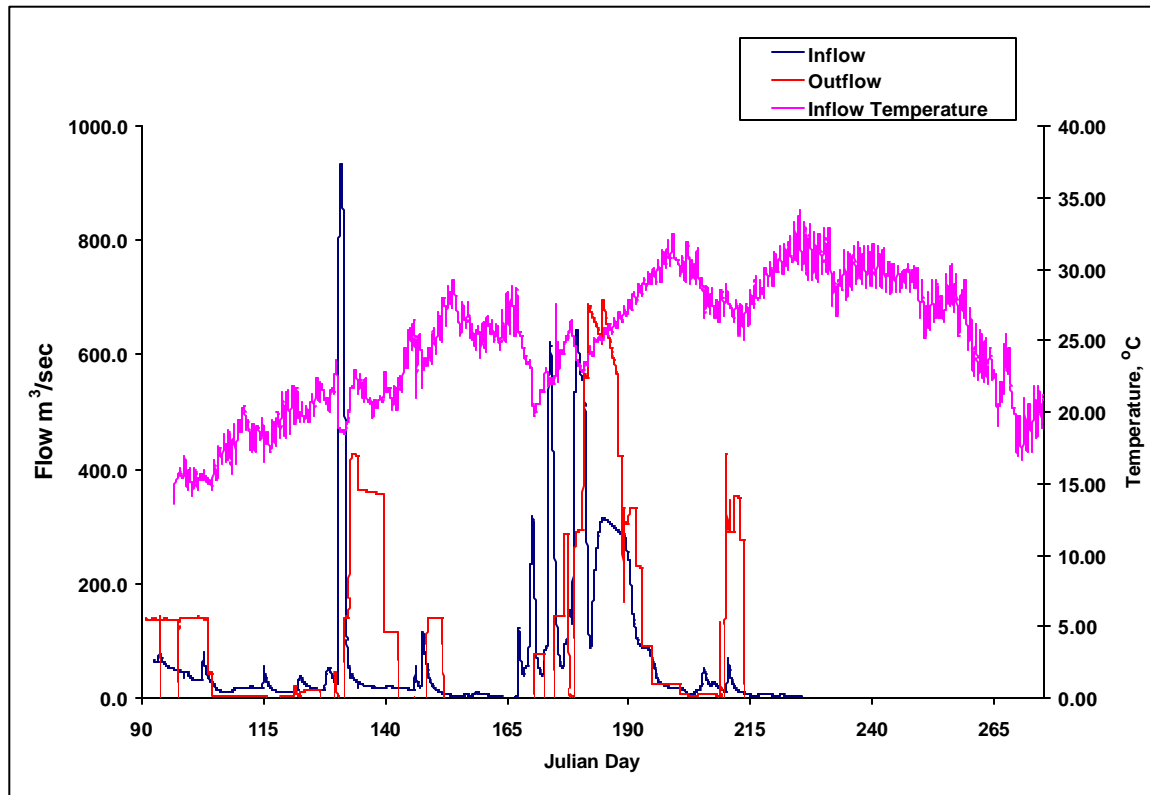


Figure 2-4
Inflows, outflows, and inflow temperatures for Oologah Modeling Study

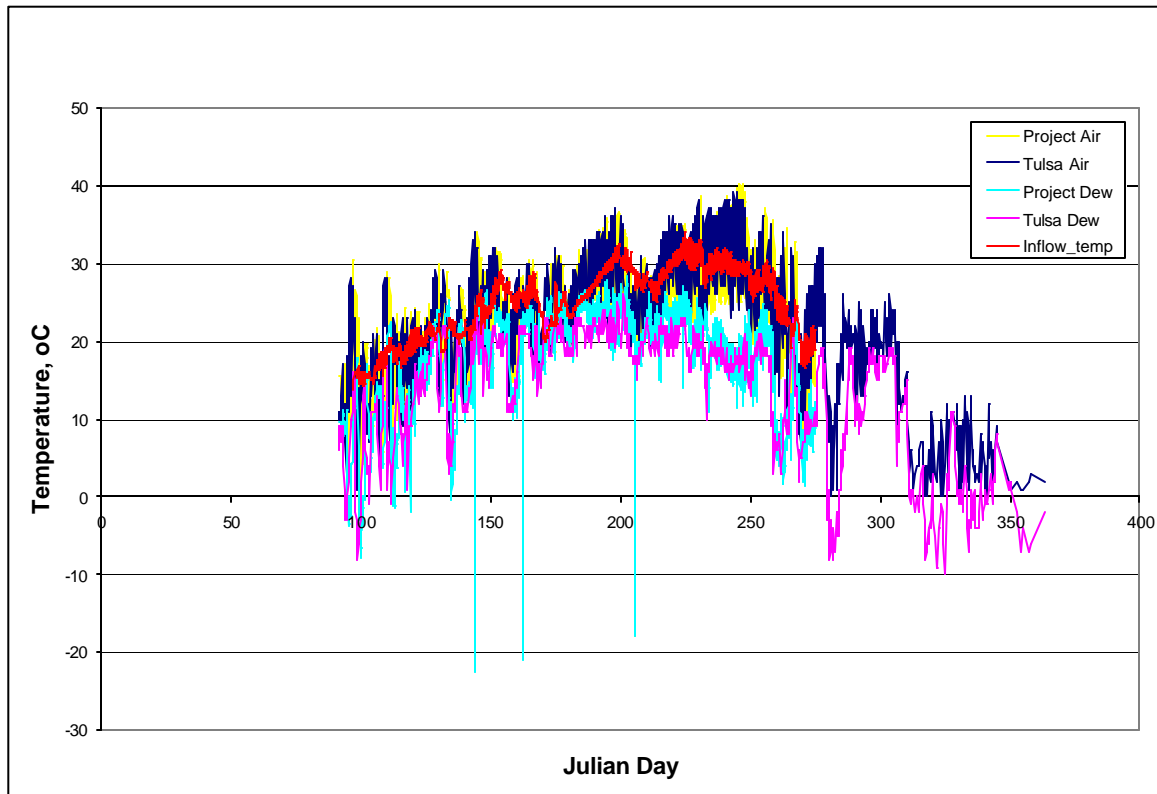


Figure 2-5
Air and dew point temperature measured at project and at Tulsa, OK

$$\frac{ug\ chla}{l} * \frac{mg}{10^3 ug} * \frac{gm}{10^3 mg} * \frac{10^3 l}{m^3} * 65 \frac{gm\ OM}{gm\ chla} = \frac{0.065\ gmC}{m^3} \quad (5)$$

It was assumed that the chlorophyll *a* measurements were corrected for pheophytin according to procedures in Standard Methods (1985).

Meteorological Data

Hourly meteorological data for 2000 were furnished by the CESWT from a meteorological recording station at the project. Hourly meteorological data for the same year were also obtained for Tulsa, Oklahoma, from the Air Force Climatological Combat Center via the Internet address <http://www.afccc.af.mil/>. Data required by CE-QUAL-W2 for surface heat exchange include air and dew point temperatures, wind speed and direction, and cloud cover. Figures 2-6 through 2-8 show meteorological data used during the study.

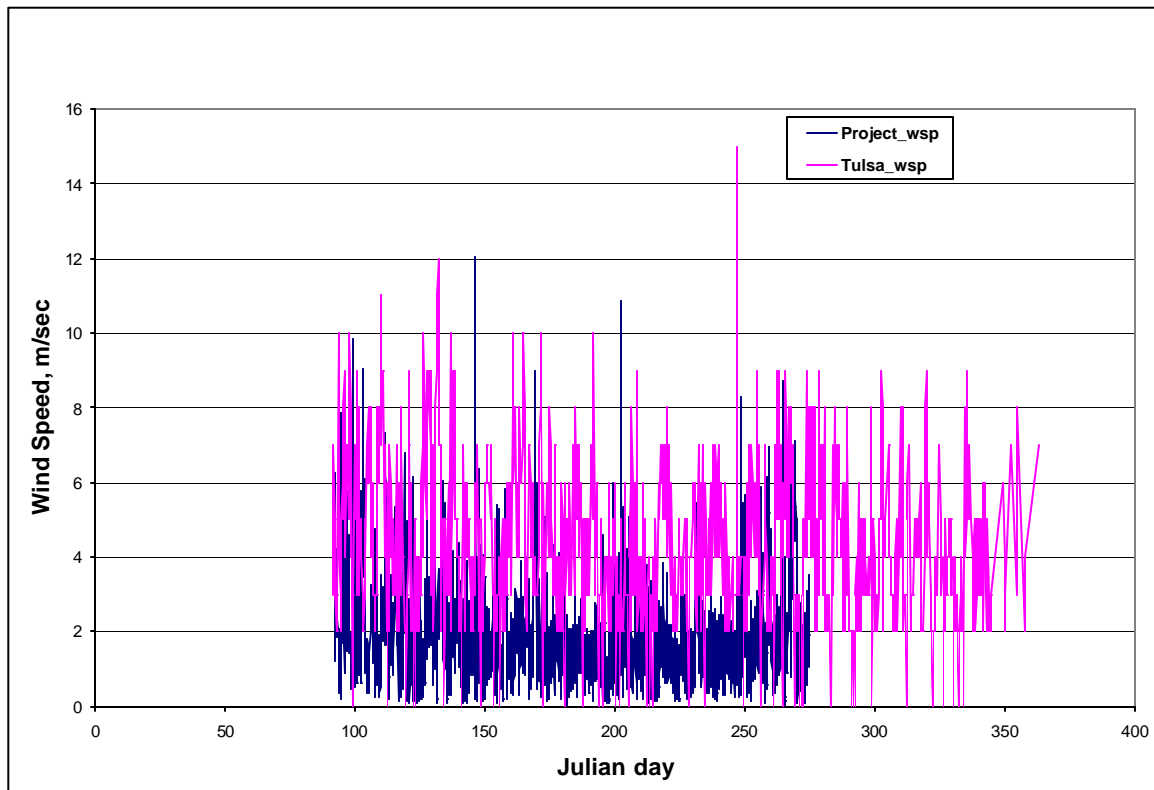


Figure 2-6
Wind speed measures at project and Tulsa, OK

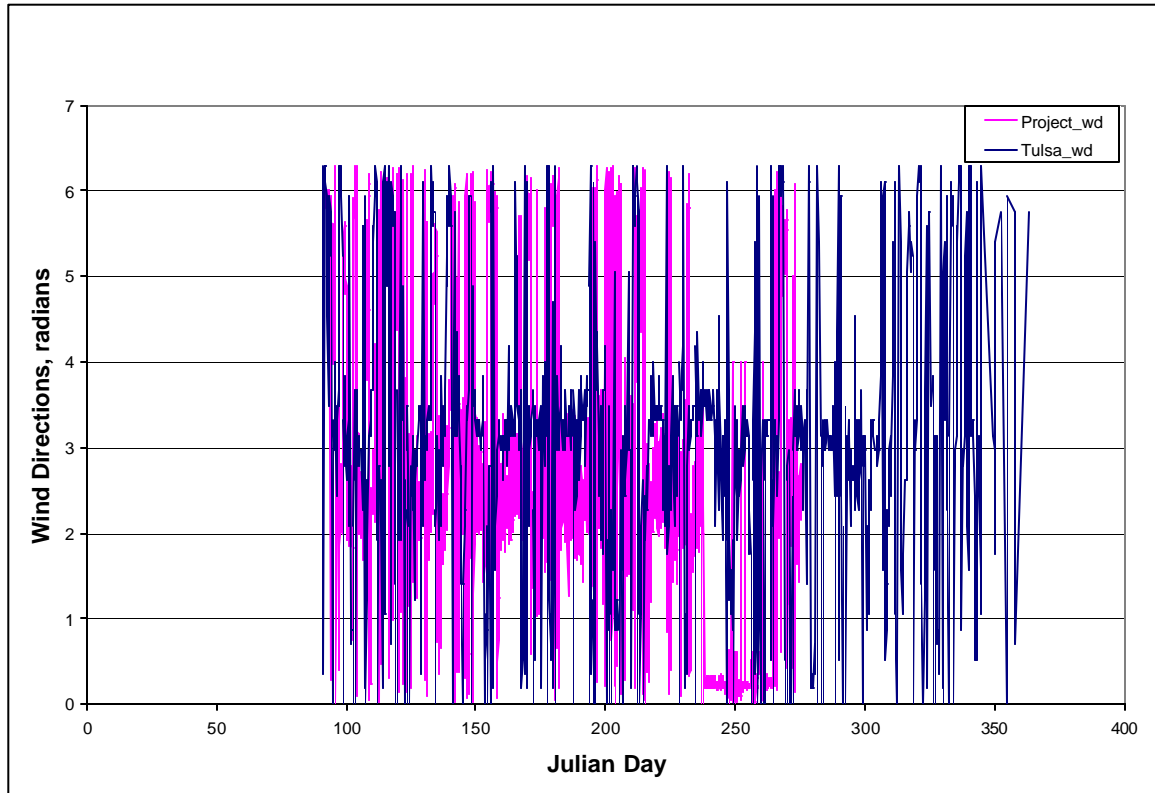


Figure 2-7
Wind direction measured at the Oologah Reservoir and Tulsa, OK

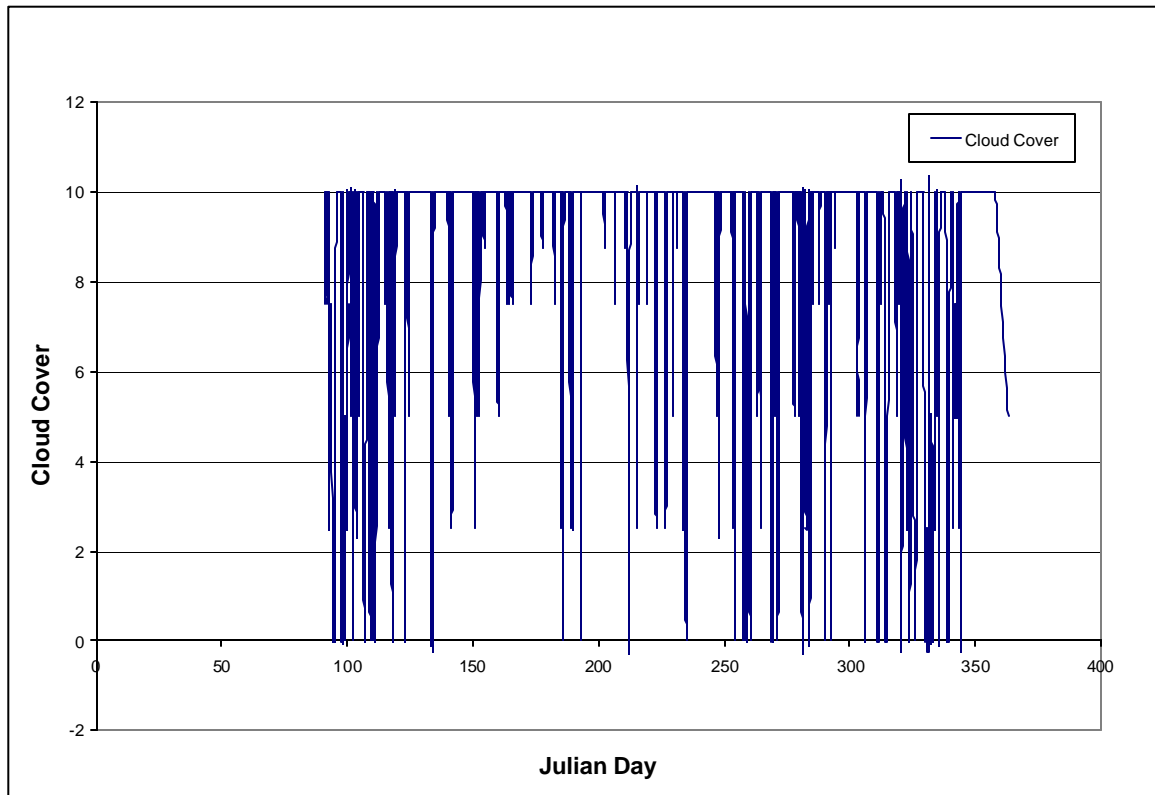


Figure 2-8
Cloud cover measured at Tulsa, OK

3 Calibration

The concept of calibration/verification of a model has changed in recent years. Previously, calibration was performed first for a chosen year with coefficients being adjusted to give best results. Verification involved applying the model to another year using the same coefficients as determined during calibration but changing boundary conditions and seeing how well the model performed. If results for the verification year were unsatisfactory, both years were revisited and coefficients adjusted until an adequate fit was achieved for both years, essentially making both data sets calibration years. Thus, including additional years for calibration further obscures the distinction between calibration and verification data sets.

Successful model application requires calibrating the model to observed in-pool water quality. If at all possible, two or more complete years should be modeled with widely varying flows and water surface elevations, if corresponding water quality data are available. Calibration began with data from the year 2000, which was the first year a complete water quality data set was collected.

Graphical comparisons of computed versus observed data were made to evaluate model performance. When interpreting temperature and water quality predictions from CE-QUAL-W2 for this study, two key points need to be made. First, temperature and water quality predictions are averaged over the length and width of a cell, whereas observed data are collected at a specific point in the reservoir. Second, measurement errors can exist with regards to measured depths, temperatures, water quality, and meteorological data. As a consequence, expecting the model to match the observed data exactly is unrealistic.

Two statistics were used to compare computed and observed in-pool observations. First, a root mean square error (RMS) was calculated to evaluate model performance and is indicated on each graph. The RMS was calculated as:

$$RMS = \sqrt{\frac{\sum (Predicted - Observed)^2}{number\ of\ observations}}$$

The RMS is a measure of variability between predicted and observed concentrations (e.g., an RMS of 0.50 means predicted data are within 0.50 of the observed value 67% of the time).

Also indicated on each plot is the mean absolute error (MAE). The MAE represents the absolute average error as compared with observed data and is calculated as:

$$MAE = \frac{\sum |Predicted - Observed|}{number\ of\ observations} \quad (7)$$

Temperature calibration has been completed with satisfaction for the 2000 data. Table 3-1 shows final values of all coefficients that affect temperature. Temperature predictions were most sensitive to changes in the wind-sheltering coefficient and meteorological conditions.

Table 3-1
Hydraulic/Thermal Coefficient Calibration Values

Hydraulic Coefficient	Variable	Oologah
Horizontal eddy viscosity	AX	$1.0 \text{ m}^2 \text{ s}^{-1}$
Horizontal eddy diffusivity	DX	$1.0 \text{ m}^2 \text{ s}^{-1}$
Chezy bottom friction factor	CHEZY	$70 \text{ m}^{1/2} \text{ s}^{-1}$
Wind-sheltering	WINDSH	1.0
Fraction solar radiation absorbed at water surface	BETA	0.45
Light extinction	GAMMA	0.45 m^{-1}
Coefficient of bottom heat exchange	CBHE	$7.0 \times 10^{-8} \text{ }^\circ\text{C m}^{-1} \text{ s}^{-1}$
Sediment temperature	TSED	$14 \text{ }^\circ\text{C}$

Water Surface Elevation

Water surface elevations are predicted by the model based on the interactions between inflows, outflows, evaporation, and precipitation. Because inflows provided include the effects of evaporation and precipitation, these options were not turned on during calibration. As shown in Figure 3-1, predicted water surface elevations closely matched the observed elevations with greatest differences occurring at the two peaks.

Temperature

Results for temperature calibration at station OO1-1 are shown in Figure 3-2. This station is closest to Oologah dam. Results for the other stations are available but will not be presented. Initially, CE-QUAL-W2 was over predicting the epilimnetic temperatures and under predicting the metalimnetic and hypolimnetic temperatures. In discussing the calibration with personnel at CESWT, it was recommended that different wind speeds be used since project wind speeds are suspect. Thus, meteorological data from Tulsa, Oklahoma, were obtained and compared to project meteorological data (Figures 2-6 through 2-8). Meteorological data between Tulsa and the project were similar except for wind speed which was lower at the project. Once Tulsa wind speeds replaced project wind speeds, and solar radiation was adjusted for Greenwich Mean Time, temperature calibration was completed with favorable results for this year. From Figure 3-2, RMS values are less than $1 \text{ }^\circ\text{C}$. CE-QUAL-W2 was able to capture the slight stratification occurring in June, July, and August 2000 between times of non-stratification.

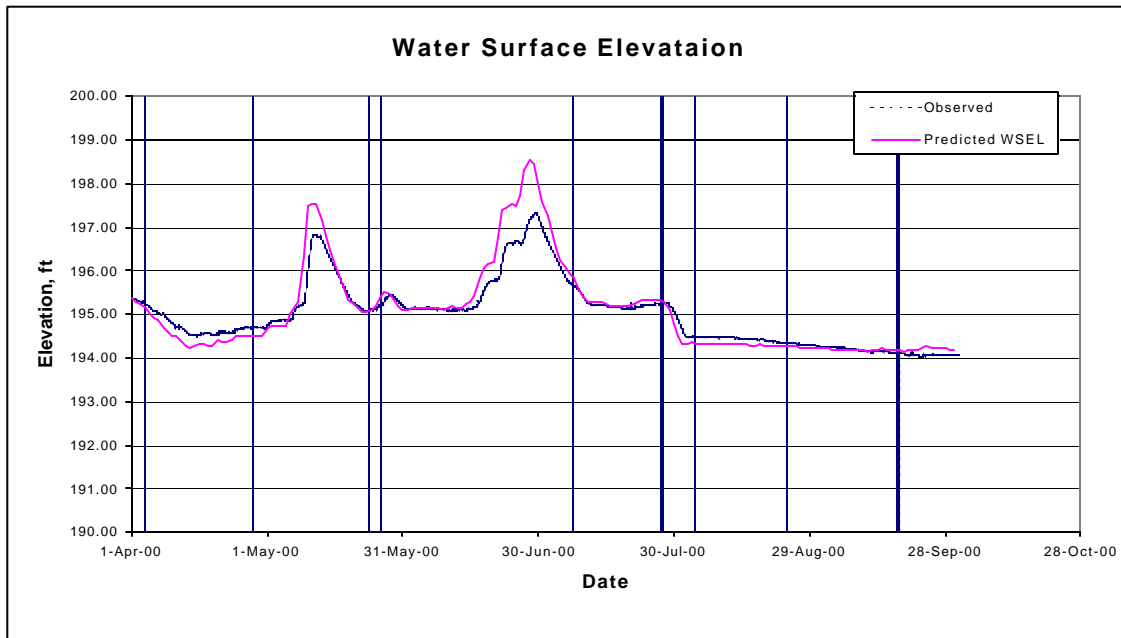


Figure 3-1
Computed (C) versus observed (---) water surface elevations

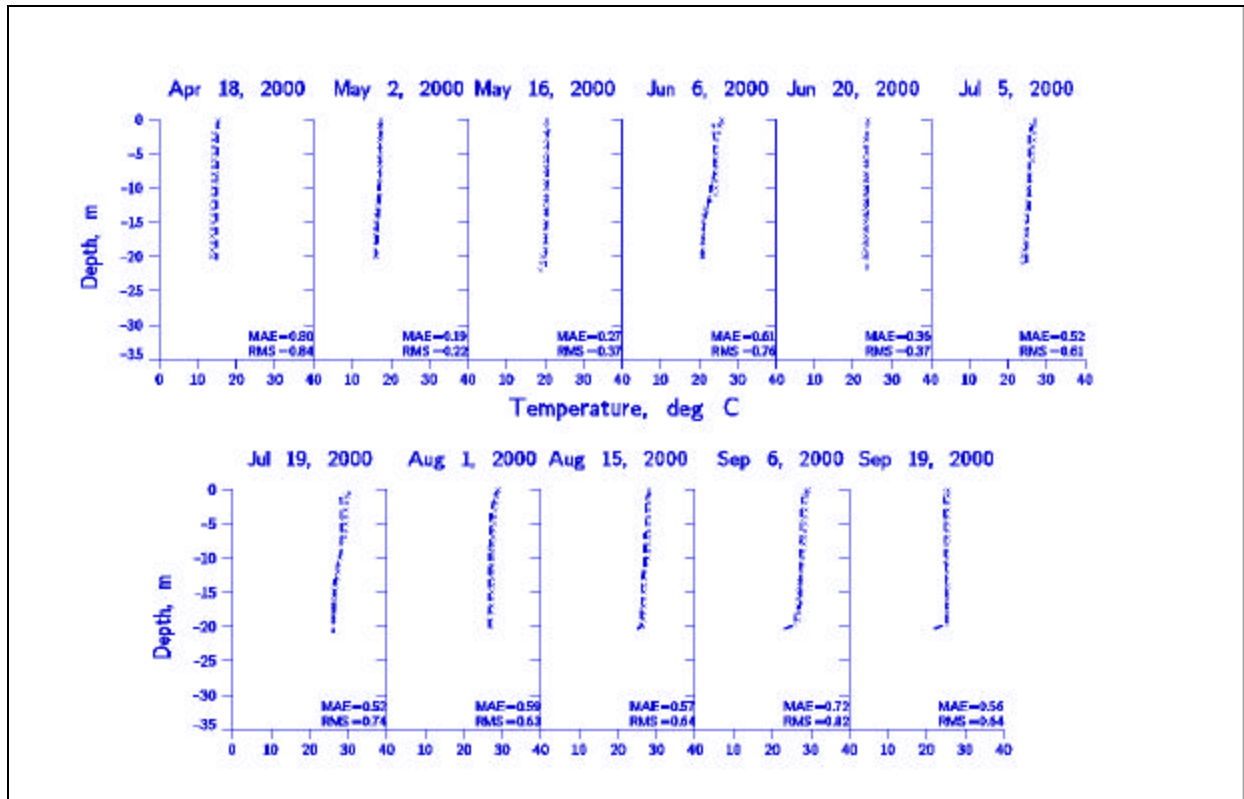


Figure 3-2
Oologah Reservoir computed versus observed temperatures at the dam

4 Summary

The ERDC was requested by the CESWT to assist in the development of a tool to assist in determining watershed management practices on water quality in the Oologah Reservoir. CEQUAL-W2 was chosen as the model to be applied to Oologah Reservoir. In the summer of 2000, the bathymetry was developed from digitized data provided by the CESWT. Additionally, initial condition and boundary files were developed for temperature calibration. Updates were made to the bathymetry file in the summer of 2001 upon receiving an updated digitized data file from CESWT. From this new digitized data file, a volume-elevation curve was developed. The only observed volume-elevation curve available for comparison was from 1977, which was considered obsolete. Calibration was completed for temperature with good comparisons of water surface elevations (0.5 meters or less difference) and an overall RMS value of approximately 0.7 for temperature at the dam station.

Water quality calibration will continue in 2002 to include all other water quality constituents collected during the year 2000. Observed temperature and DO data collected during 2001 were received and will be included in calibration as the study continues.

5 References

- American Public Health Association, American Water Works Association, and Water Pollution Control Federation. (1985). *Standard methods for the examination of water and wastewater*. 16th ed., Washington, DC.
- Brown, L. C., and Barnwell, T. O., Jr. (1987). “The enhanced stream water quality models QUAL2E and QUAL2E-UNCAS: Documentation and user manual,” Environmental Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Athens GA.
- Cole, T. M., and Buchak, E. M. (1995). “CE-QUAL-W2: A two-dimensional, laterally averaged, hydrodynamic and water quality model, Version 2.0,” Instruction Report EL-95-1, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.
- U.S. Army Corps of Engineers, Tulsa District. (2000). “Project Work Plan Oologah Lake, Oklahoma, Watershed Study.” Draft Final Report